THE UNIVERSITY OF ALBERTA

THE EFFECT OF BREATHING HIGH CONCENTRATIONS OF OXYGEN ON TREADMILL PERFORMANCE AND SELECTED PHYSIOLOGICAL VARIABLES

A THESIS

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DAVID A. CUNNINGHAM

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Effect of Breathing High Concentrations of Oxygen on Treadmill Performance and Selected Physiological Variables" submitted by David A. Cunningham in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

It was the purpose of this study to investigate the effects of breathing high concentrations of oxygen (70-73 percent oxygen in nitrogen) on treadmill performance and on the exercise and post-exercise pulse rate and the relationship between excess lactic acid production and oxygen debt.

Seven relatively fit students and faculty members of the University of Alberta served as subjects for this experiment. The subjects participated in repeated tests for both the oxygen and air trials. Each subject underwent a preliminary maximal oxygen intake test to determine the treadmill grade at which he reached his maximal oxygen intake. The subsequent maximal performance trials were run at this predetermined treadmill grade.

During each maximal performance trial the following information was recorded: time to reach exhaustion; pre-exercise, exercise and post-exercise heart rate; pre-exercise and post-exercise oxygen intake; and lactic and pyruvic acid levels. The results showed a statistically significant improvement in treadmill performance time for the oxygen trials as compared to the air trials. The oxygen debt was significantly reduced for the first minute of recovery for the oxygen trials, despite the significantly longer performance time. There was no difference in the oxygen debt between the oxygen and air trials after the first minute of recovery. The oxygen debts of both trials approached an asymptote by the eighth minute of recovery.

Little difference was observed between the recovery levels of pyruvic acid after the air and oxygen trials. The lactic acid levels were observed to be lower after the oxygen trials as compared to the air trials. The mean peak values of excess lactic acid found during the third minute of recovery was significantly lowered by the breathing of high concentrations

of oxygen during an exhaustion run on the treadmill. This was evident even though the mean performance time while breathing oxygen was significantly longer.

A relationship was observed after the third minute of recovery between excess lactic acid and oxygen debt but not between the lactic acid and oxygen debt. Breathing high concentrations of oxygen during the maximal performance did not alter the apparent relationship between excess lactic acid and oxygen debt or the apparent lack of relationship between lactic acid and oxygen debt.

The relationship between excess lactic acid and oxygen debt did not appear to be a one to one relationship. The increase in excess lactic acid during the eight minutes of recovery was greater than the increase in oxygen debt.

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CHAPTER I

STATEMENT OF THE PROBLEM

<u>Introduction</u>. There are many reports in the literature that show the effects of breathing high concentrations of oxygen on physiological processes. The most extensive of these reports is by Asmussen and Nielsen (1), with work performed at a sub-maximal level on a Krogh bicycle ergometer. Blood lactate level and respiratory metabolism were recorded while the subject breathed 1) air and 2) oxygen. A similar experiment was later conducted by Bannister and Cunningham (2), with the purpose of duplicating the results of Asmussen and Nielsen, during hard work.

The main difference between these two experiments was observed in the intensity of the exercises. Hard exercise as used in the Bannister and Cunningham experiment was considered to be that work load which enabled the subject to reach the "breaking point" in six to nine minutes while breathing air. There was considerable variability in the time taken to reach the breaking point. The term breaking point was considered to be the point at which the subject began anaerobic work.

As part of three subsidiary experiments by Bannister and Cunningham the subjects ran to exhaustion using the work load described above. The intensity of this work load was not of a maximal nature and, at times, the subjects never reached a breaking point while breathing high concentrations of oxygen. The main results of this experiment were:

1. The addition of oxygen to the inspired air always improved performance.
2. With 66 percent oxygen some of the subjects did not reach a breaking point within twenty-three minutes.

3. Discomfort experienced during work while breathing air was not felt when the subjects breathed higher concentrations of oxygen. However, when 100 percent oxygen was breathed the subjects never felt free from discomfort.
4. Oxygen breathing lowered pulmonary ventilation and blood lactate response.
5. On all physiological functions studied, 33 percent oxygen had a smaller effect than did 66 or 100 percent oxygen, and no systematic difference could be detected between the effects of 66 percent and 100 percent oxygen on respiration.

There are, at the present time, no studies in the literature similar to the experiment conducted by Bannister and Cunningham in which the subjects exercised at a maximal work load on the treadmill. Maximal work load is defined herein as that individual work load which enables the subject to reach his maximal oxygen intake after 2½ minutes. In this experiment, 70 - 73 percent oxygen will be used.

The maximal oxygen intake test, described by Mitchell, Sproule and Chapman (3), was used to determine the maximal work load. In this test, a speed of 6 mph. and a zero grade were used as a starting point for each trial. The grade was subsequently increased 2.5 percent each trial. It was felt that a slight alteration should be made in this procedure, since Mitchell, et. al., found that some young normal subjects did not reach maximal oxygen intake even at a grade of 14.75 percent and at a speed of 9 mph. It was decided, therefore, to change the starting speed to 8 mph.

The Problem. The problem is to show the effects of breathing high concentrations of oxygen on treadmill performance during maximal work. The sub-problems to be investigated are:

1. The relationship between excess lactate acid production and oxygen debt while breathing air and high concentrations of oxygen during recovery from maximal work.
2. The relationship between pulse rates while breathing air and high concentrations of oxygen during maximal work.
3. The relationship between pulse rates while breathing air and high concentrations of oxygen during recovery from maximal work.

The Delimitations.

1. The subjects are relatively fit students and faculty members at the University of Alberta.
2. The effects of breathing high concentrations of oxygen will be studied on treadmill performance.
3. The high concentrations of oxygen used were between 70 and 73 percent oxygen in nitrogen.

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CHAPTER II

REVIEW OF THE LITERATURE

The Effect of Oxygen on Performance, Blood Lactate and Oxygen Debt.

The early studies in this area were begun at the turn of the present century, primarily through the efforts of two men, Leonard Hill and Martin Flack. One of their earliest experiments, reported in 1909 (1), had some students run up and down stairs as fast as possible a prescribed number of times with and without oxygen administered before and after each run. The subject did not know whether he received air or oxygen. The blood pressure, pulse frequency, respiratory frequency and breathing volume were recorded. The results showed that when oxygen was administered the time for the run was lowered, the pulse frequency was kept down, the blood pressure was kept up, a feeling of relief to dyspnoea was observed, the subjects breathed easier and felt fitter after oxygen runs and the breathing volume and frequency were not changed. At the end of a week of running, the subjects, with the prospect of oxygen at the end of the run, ran 1050 yards without stopping. The same subjects would not run 700 yards the following day when oxygen was not administered. The authors (1:XXXIV) concluded that it " . . . shows most strikingly how oxygen restores the vigour by lessening the pulse frequency, markedly increasing its strength and fitness, and raising the blood pressure."

There would appear to be fundamental weaknesses in the study by Hill and Flack (1). However, studies such as this one were instrumental in kindling future research in the area. Pembrey and Cook (2) investigated the causes of dyspnoea and reported that oxygen appeared

to be a factor. They investigated this relationship upon man during rest and directly after exercise. It was found that at rest, oxygen appeared to have little or no effect upon the volume of gas breathed in a given time. The subjects were then exercised and it was shown that the subject had less difficulty in breathing oxygen than air. It was noted that the subject was able to recognize whether he was breathing air or oxygen due to the postponement of distress.

In December, 1909, Hill and Mackenzie (3) tested the number of times a 60 pound weight could be lifted 19 inches while holding the breath before the "bursting" point was reached. The exercise was performed three times: first while breathing quietly, second by forced breathing and third while breathing oxygen.

It was recorded that all subjects performed better after breathing oxygen. Breath holding was also considerably longer after breathing oxygen than after breathing air. This fact was supported in 1909 by Vernon (4) and in 1930 by Schneider (5) who claimed that two men, after a period of forced breathing and three deep breaths of oxygen, were able to hold their breath for 14 and 15 minutes. A test was also reported on a 250 yard and a half mile run. In general, the performers felt better and performed better after breathing oxygen than after breathing air.

A year later, in 1910, Hill and Flack did several experiments to study the effect of oxygen inhalation on muscular work. They concluded (6:372):

1. The inhalation of oxygen lessens the discomfort of forced breathing. It enables young men with a great power of pulmonary ventilation to go on with forced breathing for as long as 19 minutes, and to wash the CO_2 out of the body until the

alveolar tension sinks to as low as 1.4%.
It enables older men with a smaller ventilation power to breathe forcibly in comfort as long as they like, and abolishes periodic breathing in them.
. . . .

3. Oxygen inhalation allows a man to stand a much lower as well as a higher tension of CO_2 than is normal.
. . . .

6. Oxygen inhalation enables the athlete to excel by making him able to stand a higher tension of CO_2. After deep breathing oxygen and filling his lungs with the gas he can run 200-300 yards without breathing and this gives him a mechanical advantage.

7. The effect of oxygen inhalation is almost entirely spent by the first period of exertion which follows the inhalation.

The following year, Feldman and Hill (7) studied the amount of lactic acid excreted in the urine after a short period of exertion. The subjects performed work while carrying the oxygen apparatus on their back. They had no knowledge of whether they were breathing air or oxygen. They found (7:442):

. . . that after certain short periods of exertion almost no lactic acid appears in the urine if oxygen is inhaled, and a distinct amount of air is breathed. After a longer period of exertion considerably less lactic acid is excreted when oxygen is inhaled.

Furthermore this " . . . increased production of lactic acid by the muscles is due to oxygen want, and that oxygen inhalation has a favourable influence, at any rate in part, by lessening the rise of acid concentration."

Parkinson (8) found a reduction in the pulse rate when oxygen was breathed and the subject remained at rest.

Briggs (9, 10) studied the rate of exertion of subjects of various physiques who trained while breathing air and oxygen. A bicycle

ergometer was used at 56 revolutions per minute to test the subjects on work capacity. Further tests were also performed while walking up an incline. Each test was done either with oxygen added to the inspired air or without the addition of oxygen. It was found that physical work was easier for unfit men when oxygenated air was breathed than when normal air was breathed, but a similar difference was not observed in a fit man. It was noted that when work of slowly increasing intensity was performed the expired carbon dioxide percentage first rose, then fell. The load at which that percentage is a maximum is called the "crest load". As the author observed (9:310):

> If curves be drawn showing work done (abscissae) and exhaled-CO_2-percentage (ordinates), (a) when the subject breathes air, and (b) when he breathes oxygen, the curves are found to coincide up to the crest when the man is very fit and to diverge widely when he is unfit, since the CO_2-percentage becomes much lower in the unfit when only ordinaty air is breathed. A method of measuring fitness is described; it is based upon the experimental fact that fitness is inversely as the divergence of these curves.

If the work is done past the "crest load", Briggs (9) noted that even the fittest man obtains benefit from breathing higher concentrations of oxygen. The author also found that the concentration for optimal benefit from enriched air was approximately 60 percent. Above the 60 percent level, no effect during the work, even on very unfit persons, was noted.

Dautrebande and Haldane (11) studied the pressure of alveolar carbon dioxide and pulse rate when oxygen at increased pressure was breathed. The subjects breathed from a Douglas bag of oxygen or air while sitting quietly for five minutes. The pulse rate was counted and a sample of alveolar air was obtained about one second after the

completion of an inspiration, from which the carbon dioxide percentage was determined. The results showed that the respiration of oxygen increased the breathing and diminished the pulse-rate. When oxygen was breathed at normal barometric pressure, there was a drop of about 1.5 mm. in alveolar carbon dioxide pressure and approximately five beats per minute in the pulse rate while sitting. At 2.08 atmospheres the drop was about 3.5 mm. in alveolar carbon dioxide pressure and the drop in the pulse rate was eleven beats per minute. It was concluded that excess oxygen slowed down the circulation.

A. V. Hill, et. al. (12), also employing the Douglas bag method, studied the effect of inhalation of oxygen upon the metabolism during "standing running". They found that the breathing of oxygen considerably increased the oxygen intake during severe exercise as compared with that while breathing air, but diminished the rise in the respiratory quotient during and immediately after exercise. The changes in the respiratory quotient they ascribe chiefly to the large increases in oxygen intake and not to any considerable degree to changes in the carbon dioxide output. The time course of the recovery process while breathing oxygen-rich air at rest was not appreciably different from that while breathing atmospheric air. The increase in oxygen intake during exercise with inhalation of oxygen was often so large that they believed it could not be due simply to a more complete saturation of the blood with oxygen in its passage through the lungs.

In 1926, Hewlett, et. al. (13), studied the effect of breathing oxygen enriched air upon the lactic acid content of the blood and urine, and pulmonary ventilation, while the subjects performed measured

exercise. The main experiment was performed on a treadmill at a rate of 85 to 90 steps per minute. The steps were seven inches high and the subjects carried a thirty pound load for five minutes. This particular work was chosen in order to obtain a quick rise in lactic acid in the urine. The results showed that the addition of oxygen to inspired air during strenuous exercise produced subjective sensations of less effort, less shortness of breath and less fatigue. The volume of air breathed was also reported to be less. The blood lactic acid had to rise to 30 or 40 mgm. per cc. in order to appear in the urine. "It appears, therefore, that blood studies are better suited than urinary studies to show lesser changes in the lactic acid metabolism after exercise." (13:322) Inhalation of the oxygen enriched air during the exercise produced the following: it lessened the subjective sense of dysponea during and immediately after exercise, the minute volume of respiration was reduced, the concentration of carbon dioxide in the expired air was increased and the concentration of lactic acid in the blood and urine was decreased.

Clark-Kennedy and Owen (14), without giving any details regarding the type of exercise or the respiration apparatus employed, compared the metabolism during exercise with inhalation of air containing 26 and 16 percent oxygen. When air containing 26 percent oxygen was breathed, the oxygen consumption was greater than when 16 percent was inhaled, the percentage of oxygen requirement incurred as debt was less, the pulmonary ventilation and the respiratory quotient were lower, and the percentage of oxygen absorption and carbon-dioxide excretion were higher, suggesting greater lactate accumulation. Exercise described as "running all out" resulted in a greater oxygen intake and debt (more work possible) when

a high oxygen mixture was breathed and in a lower oxygen intake and debt (less work possible) when a low oxygen mixture was breathed, than when air was inhaled.

Subjects who inhaled oxygen before or after running were able, according to Miyama (as cited in 16), to increase their speed and to show more satisfactory recovery from fatigue. The total rise in blood pressure and in pulse rate was less than when breathing air and there was a more rapid recovery of normal resting blood pressure and pulse rate. Miyama believes that the oxygen removes the lactic acid produced in the muscles by bodily exercise.

Barach (15), although studying specifically the effect of oxygen in counteracting alcoholic intoxication, made some experiments under normal conditions during the exercise of mounting and dismounting a small platform. Breathing oxygen resulted in greater efficiency and ease of performance than when the subjects inhaled atmospheric air. The pulse rate was, on the average, 20 percent lower, the respiration rate 10 percent lower, and the pulmonary ventilation 13 percent lower after 2, 4 and 8 minutes of exercise with inhalation of oxygen than it was after exercise with inhalation of air.

Benedict, Lee and Strieck (16) in 1934 measured metabolism with a subject in the post-absorptive condition. This testing was done in the morning under four different conditions: (1) during quiet sitting, (2) during the transition from rest level to the work level (bicycle riding), (3) during work after a steady state had been reached, and (4) during the recovery (sitting) from work. Measurements were taken on respiratory exchange, respiration rate and heart rate while the subject breathed

either 20, 40, 60 or 90 percent oxygen. The average rate of work was 68 revolutions of the bicycle pedals per minute.

The results showed that the inhalation of oxygen-rich air had no effect on the respiration rate, either during rest or during work. The heart rate during rest was lower when the subject inhaled highly oxygenated air. During work of a constant amount the heart rate was also lower when the subject breathed oxygen-rich air.

No effect upon the oxygen consumption either at rest before work, during work, or during the recovery phase was noted, whether the gaseous mixture inhaled was ordinary air or contained a high percentage of oxygen. The intensity of the work resulted, on the average, in an oxygen consumption of 1400 cc. per minute. The rate of recovery in metabolism was the same, irrespective of the oxygen content of the air breathed. The character of the material burned in the body during muscular effort was not altered by inhalation of oxygen-rich air.

Christensen, et. al. (as cited in 23:124), stated:

> . . . that when the exercise was so severe that it could not be maintained for two minutes the addition of oxygen to the inspired air had no effect on the performance. With work of slightly lower intensity oxygen increased the endurance and the capacity for work. When, breathing oxygen, the subject started with moderate exercise and the intensity was subsequently increased by stages, he was able to maintain rates of work which had previously exhausted him within two minutes. Evidently time was required for the adjustment of the respiratory and circulatory systems to the new conditions if the extra oxygen was to produce its effect.

In 1937 Nielsen and Hansen (as cited in 17:172) found that ventilation could be lowered considerably by breathing air enriched with oxygen when the work was considered to be heavy but not when the work was considered to be light. In a later experiment in 1946 by Asmussen and

Nielsen (17), the effect of breathing oxygen-enriched air on respiration during different kinds of work was examined. The work was performed on a Krogh bicycle ergometer by both the arms and legs. The pulmonary ventilation and the respiratory metabolism were determined by the Douglas bag method and the respiratory frequency was registered on a drum. Arterialized capillary blood was collected and analyzed for oxygen content.

The results indicated that a close relationship between the degree of anaerobiosis - as indicated by the concentration of the blood lactates - and a relatively high lung ventilation existed. Oxygen breathing lowered the concentration of blood lactate when the muscles were working under partly anaerobic conditions. The lowering was also shown to be proportional to the percentage of oxygen in the inspired air. It was further discovered that in rest and during light work oxygen breathing tended to produce a slight increase in the ventilation and a decrease in alveolar pCO_2.

Dripps and Comroe (18) experimented to find the threshold of normal human respiratory and circulatory systems to anoxemia. They examined 81 individuals and found an immediate decrease in pulse rate and respiratory minute volume in 28 of 33 subjects when they breathed 100 percent oxygen. Furthermore, the effect of inhalation of 100 percent oxygen was manifested in bradycardia and reduction of cardiac output per minute.

Alveryd and Brody (19) studied the effects of breathing 100 percent oxygen upon respiration, pulse frequency and blood pressure during rest. They found that the expiratory volume and respiratory frequency increased. The vital capacity decreased on the average 3.03%, the pulse frequency decreased approximately 9.1% and the blood pressure decreased.

In 1948 Asmussen, et. al. (20), studied the effect of acute anoxia on the capacity for work and on the ability to accumulate lactic acid and to contract an oxygen debt. They used two tests, a test of maximum work that could be performed at a given rate (2,000 m.kg. per minute) and a test of the shortest time necessary for performance of a given amount of work (9,860 m.kg.). Both tests were on the Krogh bicycle ergometer. The subjects breathed 12% and 100% oxygen. They found that total work performed was greatly increased with increasing the percentage of oxygen in the inspired air. The maximal oxygen consumption during work was considerably lower in 12% oxygen than in normal air. The oxygen debt seems to be slightly higher in low oxygen than in normal air, whereas the lactic acid concentration tended to be a little lower in 12% oxygen than in normal air and in pure oxygen. Time to complete a given work load was considerably increased in low oxygen and slightly decreased in pure oxygen as compared with the performance time in normal air. The maximal oxygen consumption during work when breathing 12% oxygen was much lower than in the normal experiments. The authors found that there was no large difference between oxygen debt in 12% oxygen as compared to the oxygen debt in normal air. The maximum lactic acid concentration was about the same in pure oxygen and in normal air but was higher in 12% oxygen.

They (20:62) concluded:

1. At decreased oxygen tension the capacity for work was lowered, but the maximum lactate concentration was, practically, the same or - in one type of work - higher than in normal air. Also the oxygen debt was practically the same as in normal air.

2. In pure oxygen the capacity for work was increased but the maximal blood lactate concentration was practically the same as in normal air.

Miller (21) studied the influence of oxygen administration before, during and after exercise on heart rate, blood pressure, blood lactate, endurance and subjective impressions. He used two groups of subjects: nine athletes, ages 22 to 28 and 17 non-athletes, ages 18 to 22. The exercises used were: 1) a standard four-minute run on a treadmill at 7 mph. and at a 17.5 percent grade and 2) running to exhaustion at 10 mph. and at a 17.5 percent grade. The latter exercise was used for the athletes only. Heart rate during exercise and recovery was recorded continuously. Systolic blood pressure was measured at two-minute intervals and blood lactate was sampled. Experimental and control administration were alternated in a random manner in each subject. The experimental series was the administration of oxygen for ten minutes before the exercise, during the exercise and during a twenty minute post exercise recovery period.

Miller (21:166) stated:

1. The magnitude of the increases in heart rate and blood pressure during exercise, and the rate at which they returned to normal during recovery were not altered by the administration of oxygen before, during or after the exercise.

. . . .

5. When oxygen was administered during exercise the maximal blood lactate concentration was significantly diminished in the athletes during both moderate and exhausting exercise (moderate exercise: difference of the means = 5.25 mg.%, significant at the 1% level; exhausting exercise: difference of the means = 24 mg.%, S.E. = 13.6 mg.%, significant at the 5% level). In the sedentary subjects performing moderate exercise, oxygen administration did not significantly decrease lactic acid formation (difference of the means = 12.0 mg.%, S.E. = 9.1 mg.%). The reason for this difference between athletes and non-athletes is not apparent . . .

It was further noted that there was no significant improvement in oxygen transport due to oxygen administration. The formation of lactic acid was not affected by prior administration of oxygen in moderate or heavy work. The time it took to recover from the exercise was not decreased when increased oxygen was administered. There was, however, a statistically significant increase at the 5% level in the time required to reach exhaustion (difference of the means = 1.5 minutes with a S.E. = 0.6 minutes). None of the subjects claimed that they felt better when breathing oxygen.

In 1952 Nahas, et. al. (22), investigated the oxygen saturation of blood at varying concentrations of oxygen in the inspired air. It was found that (22:179):

> . . . in vivo, a blood oxygen tension of at least 400 mm. of mercury is required to effect practically complete saturation of hemoglobin in arterial blood (temperature: 37° C. and carbon dioxide tension: 40 mm. of mercury). Arterial oxygen tensions in excess of 400 mm. of mercury can be achieved in most normal subjects by inhalation of 70 percent oxygen in nitrogen (average barometric pressure: 732.7 mm. of mercury).

In 1954 Bannister and Cunningham (23) set out to determine whether the effects described by Asmussen and Nielsen could be produced during hard exercise on a treadmill (i.e. the addition of oxygen resulting in a marked and sudden depression of respiration). The method used had two athletes and two non-athletes run on a treadmill set for a speed and gradient in order that breaking point would be reached between the sixth and ninth minutes. They breathed 33, 66 and 100% oxygen. Measurements were taken on pulmonary ventilation, alveolar pCO_2 and pO_2 and blood lactate during the exercise. The time it took to reach breaking point was also recorded.

In the first experiment the subjects breathed different concentrations of oxygen (33%, 66% and 100%). The time was recorded when the breaking point was reached. The last two experiments gave the subjects different rotations of air and oxygen. Experiment number three was the administration of air, followed by 66% oxygen, followed by air. Experiment number four administered air, 66% oxygen, air, 33% oxygen and finally air.

The results demonstrated that the addition of oxygen to the inspired air always improved performance. It was discovered that with 66% oxygen, three of the subjects did not reach a breaking point within 23 minutes. Discomfort felt during work while breathing air was not evident when the subjects breathed higher concentrations of oxygen. However, when the subjects breathed 100% oxygen they never had an elated feeling. Oxygen lowered pulmonary ventilation and blood lactate. It allowed the alveolar pCO_2 to rise to higher levels. It was also found that 33% oxygen had a smaller effect than 66% or 100%. No systematic difference could be detected between the effects of 66% and 100% oxygen on the respiratory rate.

Asmussen and Nielsen (24) found that during oxygen breathing in heavy work, the effect on the pulse frequency was the same as during rest and that oxygen breathing had no measurable effect on the cardiac output.

Aldubi (25) investigated the effect of pure oxygen intake on the physiological cost of standard work-load exercises. Aldubi exercised his subjects (six in number) on two work-loads, a moderate work-load (walking on an inclined treadmill at a speed of 3.5 mph.) and a heavy

work-load (running on an inclined treadmill at 6.9 mph.). Each subject did approximately the same amount of work ($\pm$ 50 foot pounds). The physiological cost of the exercise was computed in order to determine the actual cost of the work done in terms of oxygen expenditure, over and above that used for resting metabolism. Each work-load was performed under two conditions: breathing atmospheric air and breathing pure oxygen.

It was found that the intake of pure oxygen did not increase the physiological cost of the heavy work-load exercise. It decreased the physiological cost of the moderate work-load exercise. The use of pure oxygen increased the net oxygen uptake of the period during the heavy work-load exercise, but not the net oxygen consumption of the period of moderate work-load exercise. Finally it was shown that the intake of oxygen decreased the net oxygen consumption during the recovery period of exercise of either moderate or heavy work-load.

In 1961, Margaria, et. al. (26), measured maximum oxygen consumption while breathing oxygen enriched mixtures. The exercise test was a run on the treadmill at a speed of 12 km. per hour at a 6 percent grade which caused exhaustion within 4 to 6 minutes. It was shown that (26:467):

> The maximum oxygen consumption, as measured during strenuous exercise is increased about 10% when breathing pure oxygen, of the same order of magnitude as the O_2 increase in blood.
>
> The better performance in O_2 is therefore explained as due to the increased blood O_2 available, other factors, such as a higher saturation of Hb or a faster blood circulation, having no appreciable importance.

The General Effects of Oxygen on Performance, Blood Lactate and Oxygen Debt. Several authors (27,28,29,30) have expressed general opinions on the

effect breathing high concentrations of oxygen has on various physiological variables.

In 1935 Haldane (27) reported that if oxygen were administered before a contest no physiological advantage could be found unless the contestant held his breath during the execution of his event.

Muchinger (as cited in 28:403) demonstrated that a definite improvement in performance could be reached during oxygen breathing only at levels of 300-350 watts. The increase in the performance time was 25 percent. At lesser or greater levels of work, the effect of the oxygen was much smaller. With work set at 300-350 watts, respiratory volume and heart rate decreased by some 7 to 10 percent during oxygen breathing.

Morehouse (29:175) reported:

> In laboratory tests nearly all workers agree that the administration of oxygen following exercise has little influence on the rate of recovery. This would be expected since the decrease in cardiac output after the cessation of exercise makes it possible for the blood to remain in the pulmonary capillaries long enough to achieve equilibrium with the alveolar air. There is less agreement concerning the beneficial effects of breathing oxygen just before exercise. It is difficult to explain the occasional report claiming such benefit in view of the fact that the arterial blood is virtually saturated with oxygen when room air is breathed during rest.
>
> By contrast, it is fairly generally agreed that the administration of oxygen during exercise is beneficial, though there is disagreement concerning the degree of benefit.

Karpovich (30) reported on several experiments in which oxygen administered before the start of a 100 yard swim aided performance because it increased the swimmer's ability to hold his breath. He cited a study from 1934 which showed no difference in recovery when oxygen was administered and another study which reported no benefit even if the exercise was performed to complete fatigue.

In a later study cited by Karpovich, a graduate student at Spring-

field undertook to investigate the effect of oxygen on recuperation from fatigue. The subjects ran to exhaustion on a treadmill, with the speed at 7.6 mph. and inclination 5 degrees, followed by a 10 minute rest after which they again ran to exhaustion. During the 10 minute rest the subjects breathed either oxygen or atmospheric air. Each subject was given oxygen on two of the runs without knowing whether he received air or oxygen.

The results showed that oxygen had no effect on recuperation from fatigue. "This means that the 'psychological' factor did not affect performance after fatigue caused by the first run." (30:88)

Luchsinger and Moser (28:402) stated:

> A favourable effect of oxygen breathing can be expected only if the maximum diffusing capacity is reached while the oxygen transport capacity of the circulation has not been completely used. If the oxygen demand is limited by the transport capacity of the circulation, however, oxygen breathing will have a very limited effect in permitting an increase in performance since the oxygen uptake will be increased only insofar as it is limited by insufficient diffusion or hypoventilation.

They (28) also stated that oxygen breathing during the recovery phase had no significant influence upon either the time taken to recover or the time taken to pay back the oxygen debt. They continued that because of the low threshold of the body for oxygen at this point, the amount of oxygen present in atmospheric air is almost maximal and the solubility of oxygen in the tissues and the plasma is so small that oxygen breathing before or after the performance had no significant effect in terms of increasing work capacity.

<u>The Relationship Between Oxygen Debt and Lactic Acid</u>. Hill, <u>et. al</u>. (12), were the first to relate the lactate concentrations in the blood during recovery to the oxygen debt. Margaria, <u>et. al</u>. (31), studied one subject in a series of experiments. The experiments were run on the treadmill at various grades and speeds. Their findings provided evidence in support of the proposition that the concentration of lactate in the blood during recovery was an adequate measure of the size of the oxygen debt and the rate of removal of lactate from the blood was an accurate indication of the rate of "payment" of the oxygen debt. It was also felt that the appearance of a lactate concentration in the blood above the normal was an indication of tissue hypoxia.

Recent evidence has been brought forward to show that an increase in the blood lactate concentration cannot be rigidly interpreted as being the result of tissue hypoxia. Huckabee (32) showed that intravenous infusion of pyruvate will produce major changes in the concentration of lactate without affecting oxygen consumption and with no evidence of tissue hypoxia. Huckabee developed the following equation for calculating the change in lactate concentration which may be ascribed to oxygen lack in the tissues:

$$XL = (Ln - Lo) - (Pn - Po)\ \frac{(Lo)}{(Po)}$$

where Ln and Lo are experimental and control lactate concentrations, Pn and Po are experimental and control pyruvate concentrations, and XL (excess lactate) is the fraction of the total concentration change of lactate due to tissue hypoxia.

Huckabee (33) in a later experiment studied the relationship of pyruvate and lactate during anaerobic work. The results showed that

changes in blood lactate do not correlate with oxygen debt. Calculated "excess lactate", a function of both pyruvate and lactate, was found to correlate with oxygen debt.

Knuttgen (34) investigated the relationships among oxygen debt, blood lactate, blood pyruvate, and excess lactate. A series of experiments at different work intensities was run. Blood taken from the finger tip and expired air were taken during rest, after steady-state was reached and throughout the recovery period. Blood lactate was determined by the colorimetric method of Barker and Summerson (35) and blood pyruvate was determined by the colorimetric method of Friedman and Haugen (36).

The results showed increases in lactate and pyruvate values over resting levels. The lactate reached a peak during the first two minutes of recovery followed by a steady decline. Resting levels were not reached in eighty-five minutes of recovery. The pyruvate reached peak levels three minutes after work. Resting levels were not reached after eighty minutes of recovery. There was a rapid decrease in the rate of oxygen uptake immediately after work. The oxygen uptake levels returned to resting level during the recovery periods.

Maximal Oxygen Intake Tests. The maximal oxygen intake test is a test of severe muscular work in which motivation and will power play no part. It is simply the measurement of the highest rate of oxygen intake which can be reached at a point below that of exhaustion. Hill and Lupton (as cited in 37:927) noted that each individual has a maximal level of oxygen intake which varies from one individual to another. Taylor, et. al. (38), noted that this maximal level varies for different types of work.

Keys, et. al. (39), determined the maximal oxygen intake by a three

minute treadmill run, with the speed set at 7 mph. and with the grade varied according to the capacity of the subject. The test was preceded by a twenty minute walk at 3.5 mph. and a 10 percent grade. The tests were repeated two days apart until the oxygen intake was similar on two subsequent trials. On each trial, the treadmill was raised 2.5 percent. The expired air was collected for one minute during the period from one minute, forty-five seconds to the two minute, forty- five second mark of the treadmill run.

Taylor, <u>et. al</u>. (38), developed a test similar to that by Keys, <u>et. al</u>. The test took a minimum of three days, and occasionally five days to establish work loads necessary to produce a maximal oxygen intake. The subjects warmed up in a post-absorptive state at 3.5 mph. and a grade of 10 percent for 10 minutes. Five minutes later the subjects ran at 7 mph. with a 10 percent grade which was raised 2.5 percent each subsequent run, held on separate days. If two oxygen intakes were different by less than 150 cc./min., the maximal oxygen intake was considered to be reached.

The results showed: 1) using a constant speed and increasing the grade is better than using a constant grade and increasing the speed; 2) oxygen intake apparently reached a steady state in the time alotted; 3) with an increase of 2.5% in the grade, the maximal oxygen intake increased approximately 300 cc./min.; 4) no effect was produced on maximal oxygen by increasing the speed from 7 to 8 mph. or by eating a light meal; 5) the maximal O_2 intake was increased by a warm-up and increasing the working muscle mass. The reliability of this test was found to be constant over a one year period at 0.95.

In a subsequent experiment by Buskirk and Taylor (40) several limiting factors of maximal oxygen intake were investigated. It was found that sedentary level and fat-free body weight both limited maximal oxygen intake. They also found the largest maximal oxygen intake per kilogram of fat-free weight in cross-country runners.

Slonim, et. al. (41), determined how well peak oxygen intake can be predicted from measurements made during two levels of submaximal exercise. The subjects warmed up at 3.5 mph. and at a 10% grade for 6 minutes. Thirty minutes later the subjects exercised at a constant speed of 3.5 mph. at grades of 20, 24, 26 and 28 percent for 6 minutes each until the subject was unable to complete the test. The grade was then decreased one percent until a test was found which could be completed. The tests at 20 and 24 percent grades were performed on the same day. Thereafter one test was performed each day.

Mitchell, et. al. (42), in 1955 developed a test which, with slight modification, will be used for the purpose of this study. The method is outlined below:

1. A ten minute warm-up was taken walking at 3 mph. and at a ten percent grade.
2. A ten minute rest was taken after the warm-up and after each subsequent run.
3. Following the rest period the subject ran for 2½ minutes at 6 mph. and at a zero grade. The expired air was collected during the last minute of the run. Oxygen intake was then determined.
4. The grade was increased by 2.5 percent each subsequent run until the oxygen intake levelled off or the difference between two

successive trials did not exceed 54 ml./min.

In 1959 Wyndham, et. al. (37), used a maximal oxygen intake test which was slightly different from those previously described. They trained their subjects to cycle at 70 rmp. at 7,500 ft.lb./min. for 30 minutes each day on a bicycle ergometer, after a 10 minute warm-up. After the 30 minute cycle the subjects worked to exhaustion. Heart rate and oxygen intake were recorded. The authors found that the maximal oxygen intake reached a peak very slowly and suggested that Taylor, et. al. (38), missed this slow approach of the oxygen intake to asymptote and therefore underestimated the maximal oxygen intake.

In conclusion it is evident that there are many ways to describe work capacity but as stated by Balke and Ware (43:680); ". . . the maximal oxygen consumption is the most satisfactory means of describing work capacity . . .".

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CHAPTER III

METHODS AND PROCEDURE

<u>Subjects</u>. Seven relatively fit students and faculty members at the University of Alberta were subjects for this experiment. Each subject acted as his own control - breathing atmospheric air - and as part of the experimental procedure - breathing high concentrations of oxygen.

<u>Procedure For Maximal Oxygen Intake</u>. The exercise was performed on a Quinton Treadmill, Model 18-49-B, (Speed Range 0 to 9 mph.). Maximal oxygen intake was first determined by the method described by Mitchell, Sproule and Chapman (1) with a slight modification. As previously described, the treadmill speed was changed from 6 mph. to 8 mph. The following procedures were observed by each subject:

1. A ten minute warm-up was walked at 3 mph. and at a ten percent grade.
2. A ten to fifteen minute rest, in a supine position, was taken after the warm-up and after each subsequent run.
3. Following the rest period the subject was allowed to breathe for a short period, with a nose clip in place, through a rubber mouthpiece connected to a Douglas bag by a Modified Otis-McKerrow two-way breathing valve, in order that the subject could become adjusted to breathing through the valve.
4. The first exercise run was carried out at 8 mph. and at a zero grade. The exercise time was two and one half minutes in length. The expired air was collected in a 100, 150 or 200 litre Douglas bag during the last minute of the exercise period. Oxygen intake was then determined.

5. The grade was increased by 2.5 percent each subsequent run until the oxygen intake levelled off. This procedure produced a maximal work load based on maximal oxygen intake.
6. The subject was re-tested at a later date in a similar manner in order to determine the reliability.

The expired air, collected in a Douglas bag, was analyzed for the percentage of oxygen by a Beckman Model E2 oxygen analyzer and for the percentage of carbon dioxide by a N.V. Godart Infrared Capnograph. The volume of expired air was measured by an American Meter Company Gasometer, Model 2M138 with an H.P. of 1/15 (see figures 1 and 2).

In order to find the oxygen consumption, the change in nitrogen content was used to correct the expired volume to inspired volume. The room temperature and barometric pressure were recorded before each test. The method employed is shown below:

$FeCO_2$ = % of CO_2 in expired air.
FeO_2 = " " O_2 " " ".
FeN_2 = " " N_2 " " ".

$FiCO_2$ = % of CO_2 in inspired air.
FiO_2 = " " O_2 " " ".
FiN_2 = " " N_2 " " ".

1. To find the corrected percent of oxygen:

$$x\% \text{ of oxygen } \times \frac{25}{1000}$$

2. To find the corrected volume of expired air:

VeATPD = x lt./min.

$$VeSTPD = VeATPD \times \text{the factor for reducing a vol. of moist gas to vol. occupied by dry gas at } 0^{\circ}C, \text{ and } 760 \text{ mm. } (2)$$

3. To find the volume of the inspired air:

$$ViSTPD = VeSTPD \times \frac{FeN_2}{FiN_2}$$

4. To find the volume of the inspired oxygen:

$$VO_2 = (ViSTPD \times FiO_2) - (VeSTPD \times FeO_2)$$
$$= x \text{ lt./min.}$$

Procedure For Lactic and Pyruvic Acid Analysis. A pediatric scalp vein infusion set was used to obtain blood before and after the maximal run. The needle was inserted in a forearm vein (see figure 3). The needle and polyethylene catheter were held in place by tape during the maximal run (see figure 4). Heparinized normal saline was used to prevent clotting of the blood within the polyethylene catheter.

The blood pyruvate was analyzed according to the method described by Friedman and Haugen (3), and the blood lactate was analyzed according to the method described by Barker and Summerson. (4)

Procedure For Maximal Performance Trials. After the individual maximal work load was established the subject ran to exhaustion in six separate trials, held two to three days apart; the subject breathed air or 70 to 73 percent oxygen in nitrogen. The administration of air and oxygen was alternated with each trial. Half of the subjects received air on their first test and half received 70 to 73 percent oxygen. The subjects performed all trials while breathing through the Modified Otis-McKerrow valve. The valve was connected to a Collins Chain Compensated Gasometer (capacity 600 litres) on the intake side and a system of Douglas bags on

the output side. The breathing valve was suspended from the subject's head-gear (see figure 5). The intake and output tubes were carried by an overhead suspension (see figure 6). The valve connected to the gasometer was opened at the beginning of the maximal run. At the finish of the run the valve was closed, the subject breathed atmospheric air and expired into a Douglas bag.

During the maximal exercise tests, the following procedures were observed:

1. Pre-exercise standing pulse rate was recorded by an Electronics for Medicine Inc. Electrocardiograph for 60 seconds prior to the exercise period.
2. The subject's expired air was collected for one minute before the exercise period began.
3. The time to reach exhaustion was recorded to the nearest second.
4. During the exercise period the pulse rate was recorded by the electrocardiograph for a 5 second period every 30 seconds until the run was finished.
5. Following the maximal run there was an eight minute recovery period during which the subject stood at the treadmill. Pulse rate was recorded every 30 seconds for a 5 second period. The expired air was collected serially in five bags, the first three for one minute each, the fourth for two minutes and the last for three minutes. The expired air was analyzed by the methods previously outlined.
6. Lactic and pyruvic acid analysis was performed on each subject once under the two conditions of breathing atmospheric air and

high concentrations of oxygen. The lactic and pyruvic acid levels were measured during the eight minute recovery period. The first measurement began at the one minute mark, the second at the two minute mark, the third at the three minute mark, the fourth at the five minute mark and the fifth at the eight minute mark.

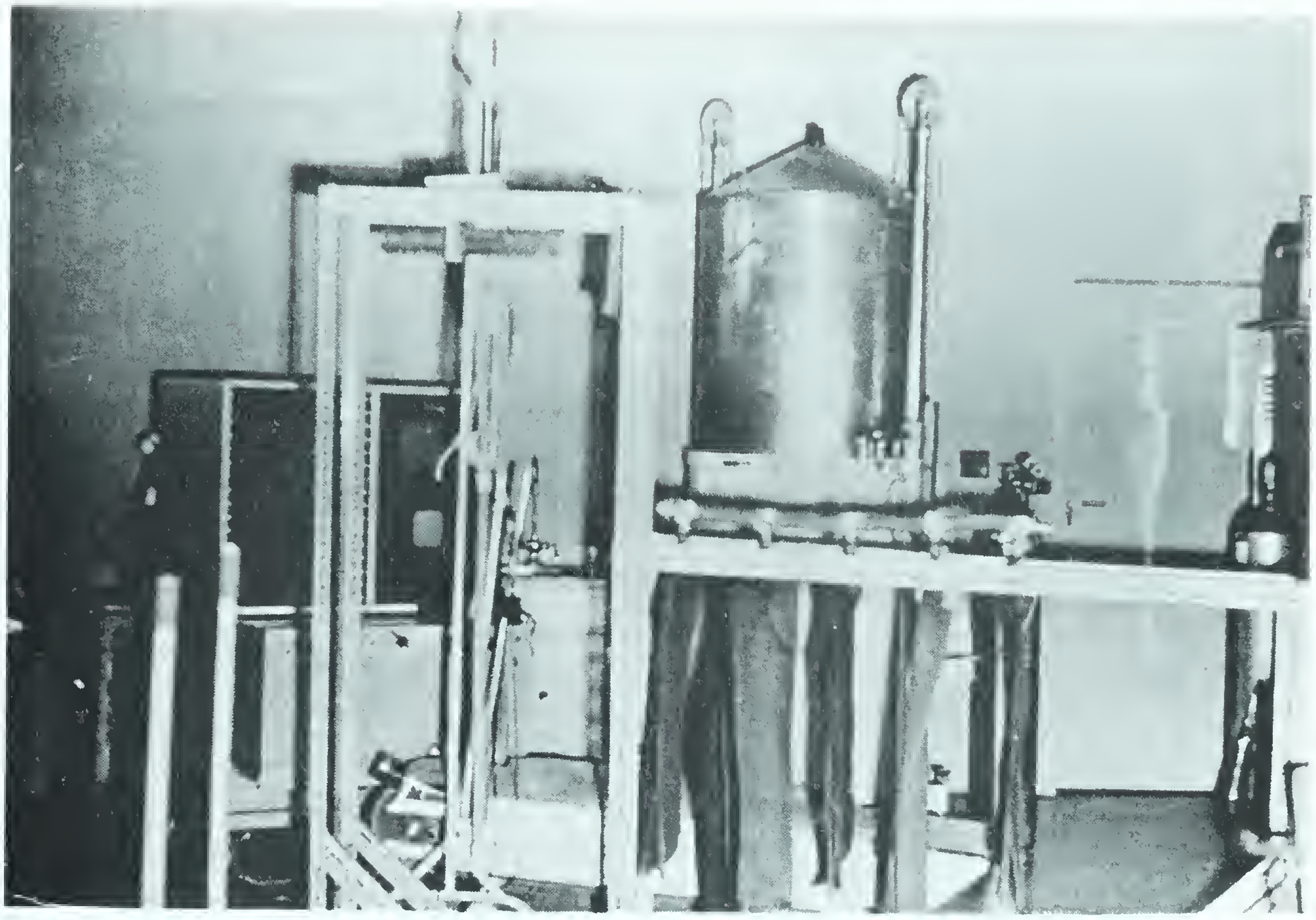

FIGURE 1. APPARATUS – Treadmill,
Douglas Bags, Gasometer
and Electrocardiograph

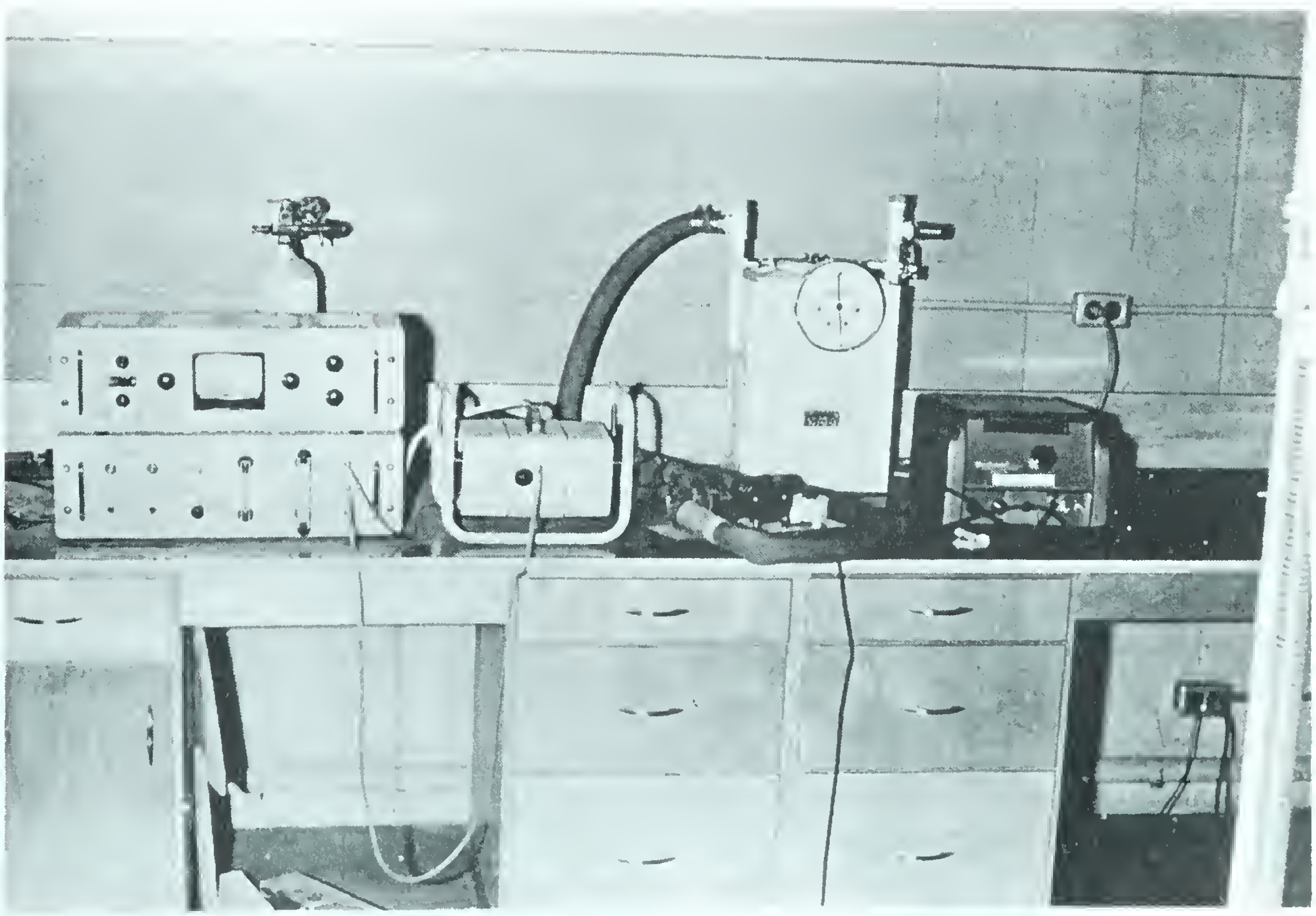

FIGURE 2. APPARATUS – Oxygenanalyzer,
Carbon Dioxide Analyzer and
Volume Gasometer

FIGURE 3. NEEDLE INSERTION –
Pediatric Scalp Vein Infusion Set

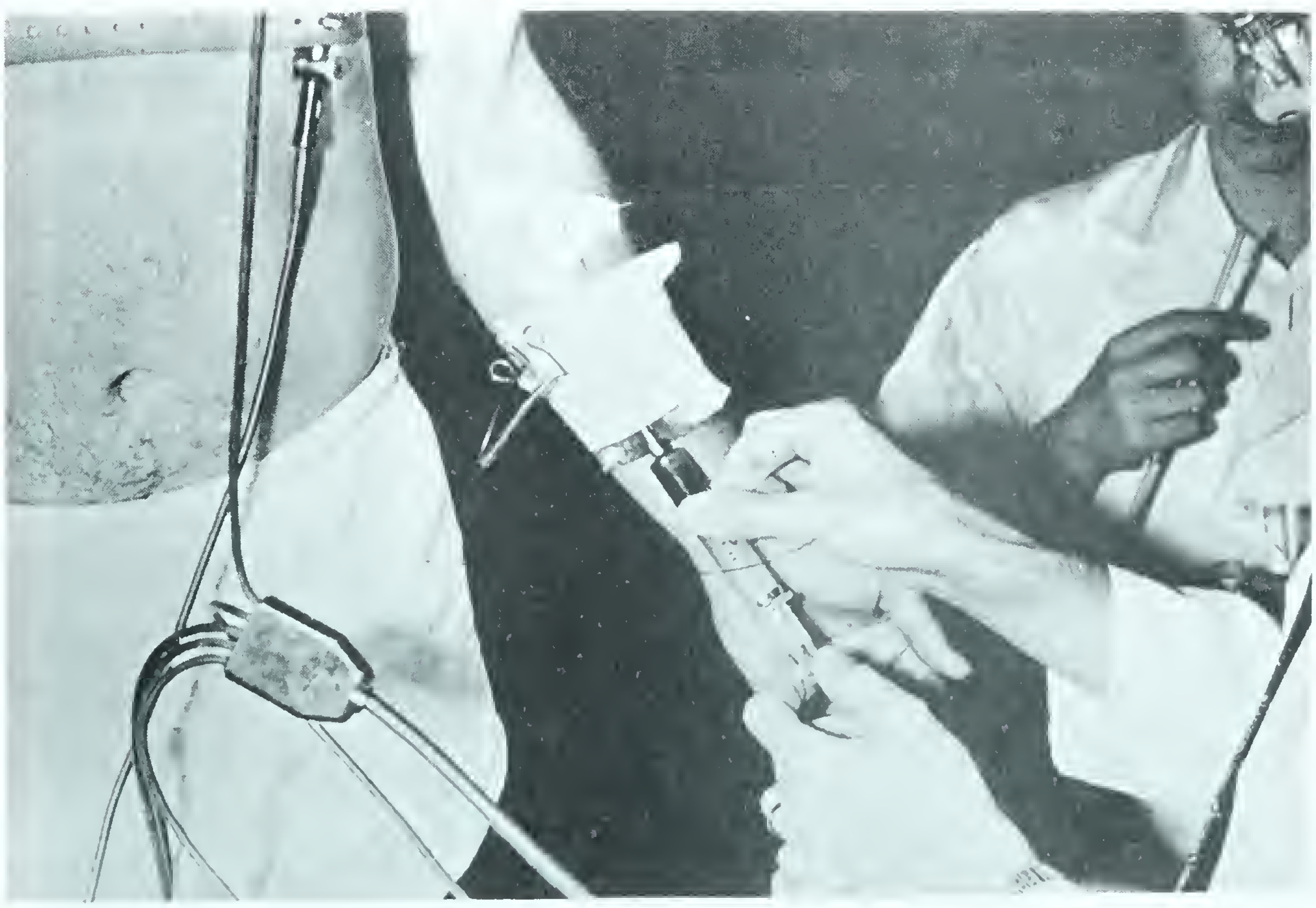

FIGURE 4. BLOOD SAMPLE – Position
of Tape and Catheter on the Arm

FIGURE 5. HEAD GEAR with MODIFIED OTIS McKERROW VALVE

FIGURE 6. MAXIMAL PERFORMANCE TRIAL
Showing Overhead Suspension

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CHAPTER IV

RESULTS AND DISCUSSION

Results

The number of subjects and the tests completed by each subject are listed in Table I. The total of the six maximal performance trials was not completed by all subjects.

TABLE I

Tests Completed By Each Subject

	Subject	Number of Tests Completed
	1	2
	2	6
	3	6
	4	4
	5	2
	6	6
	7	6
Total	7	32

Maximal Oxygen Intake. The results of the maximal oxygen intake tests are shown in figures 7, 8 and 9. Subjects 8, 9 and 10 were added for the purposes of observing the maximal oxygen intake for more subjects.

Each subject reached a definite peak value in each test. The maximal oxygen intake was taken at this peak value. Figure 10 shows the values for test 1 and test 2 plotted in a scattergram.

In only one case did a subject change the grade at which he reached his maximal oxygen intake. Subject 3 in the re-test arrived at a maximal oxygen intake at the 5 percent grade rather than at the 2.5 percent grade

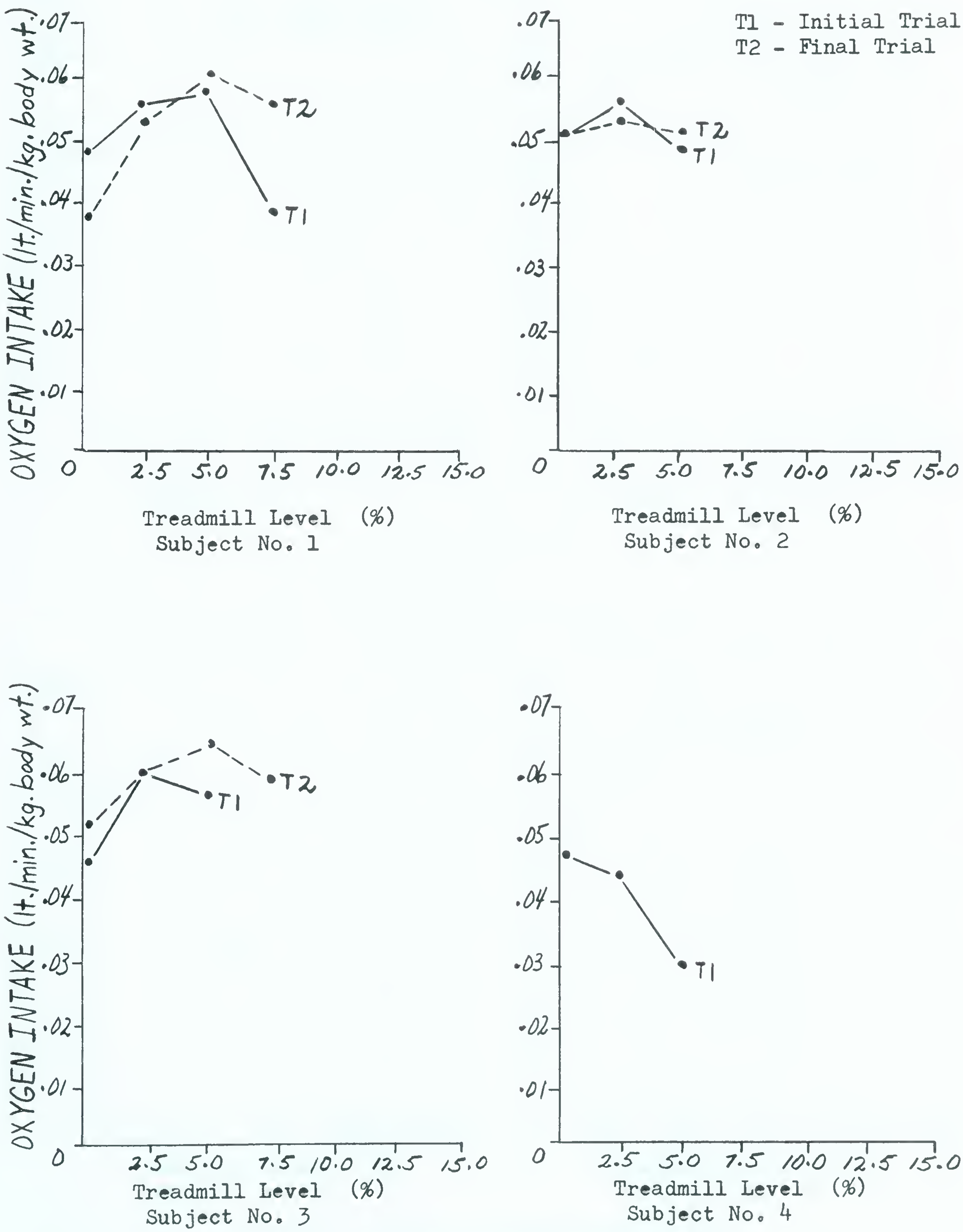


FIGURE 7 MAXIMAL OXYGEN INTAKE TESTS

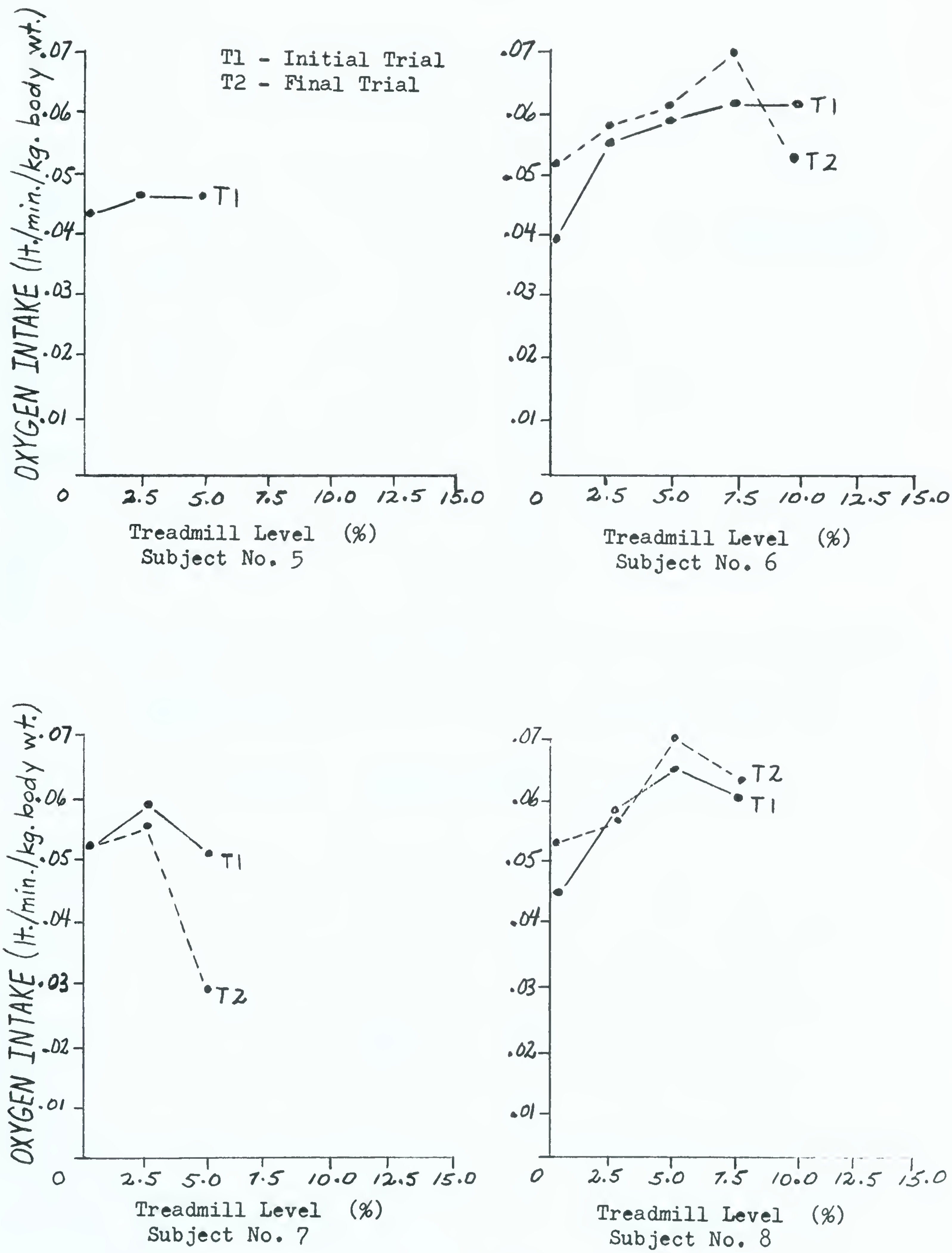


FIGURE 8 MAXIMAL OXYGEN INTAKE TESTS

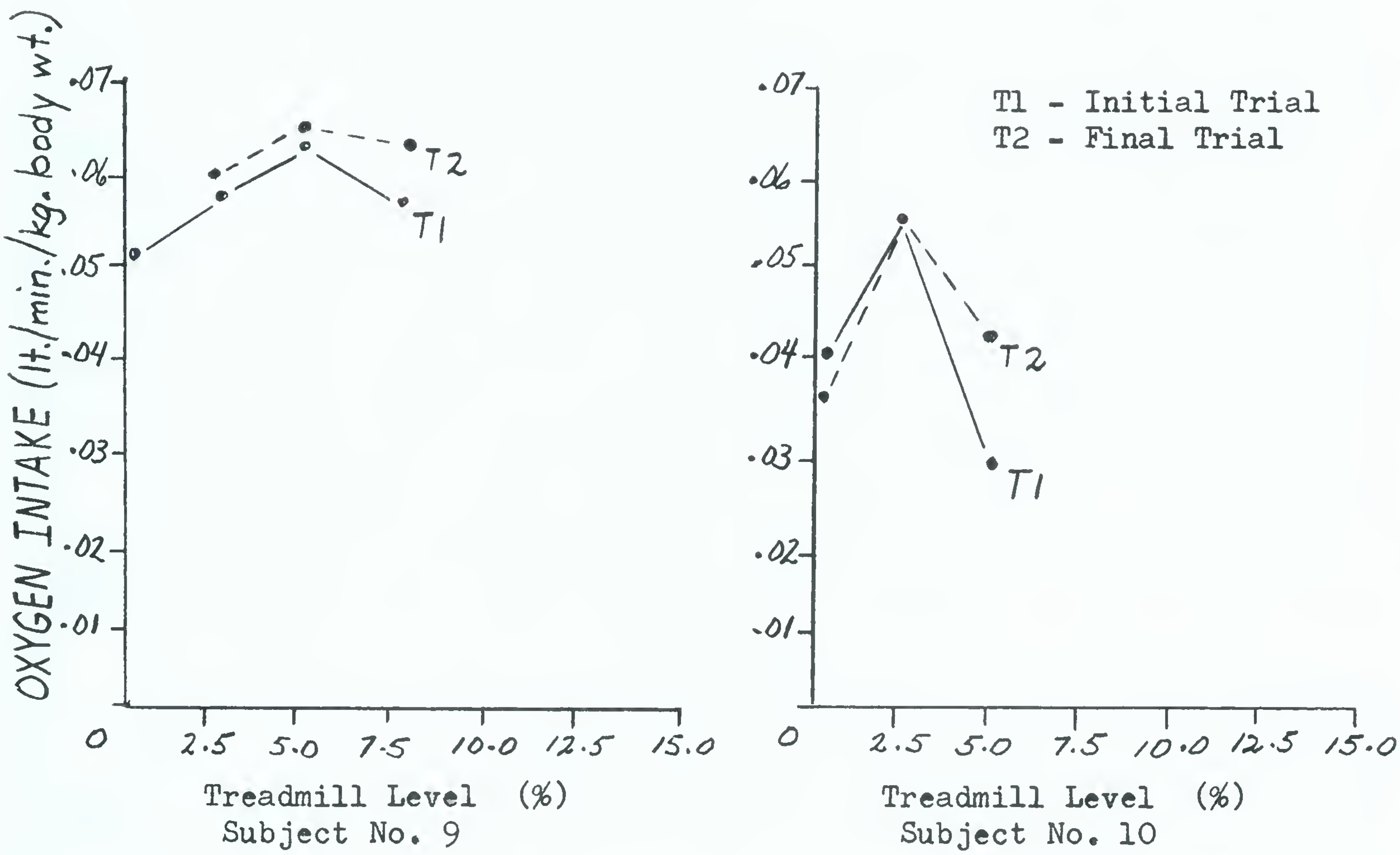
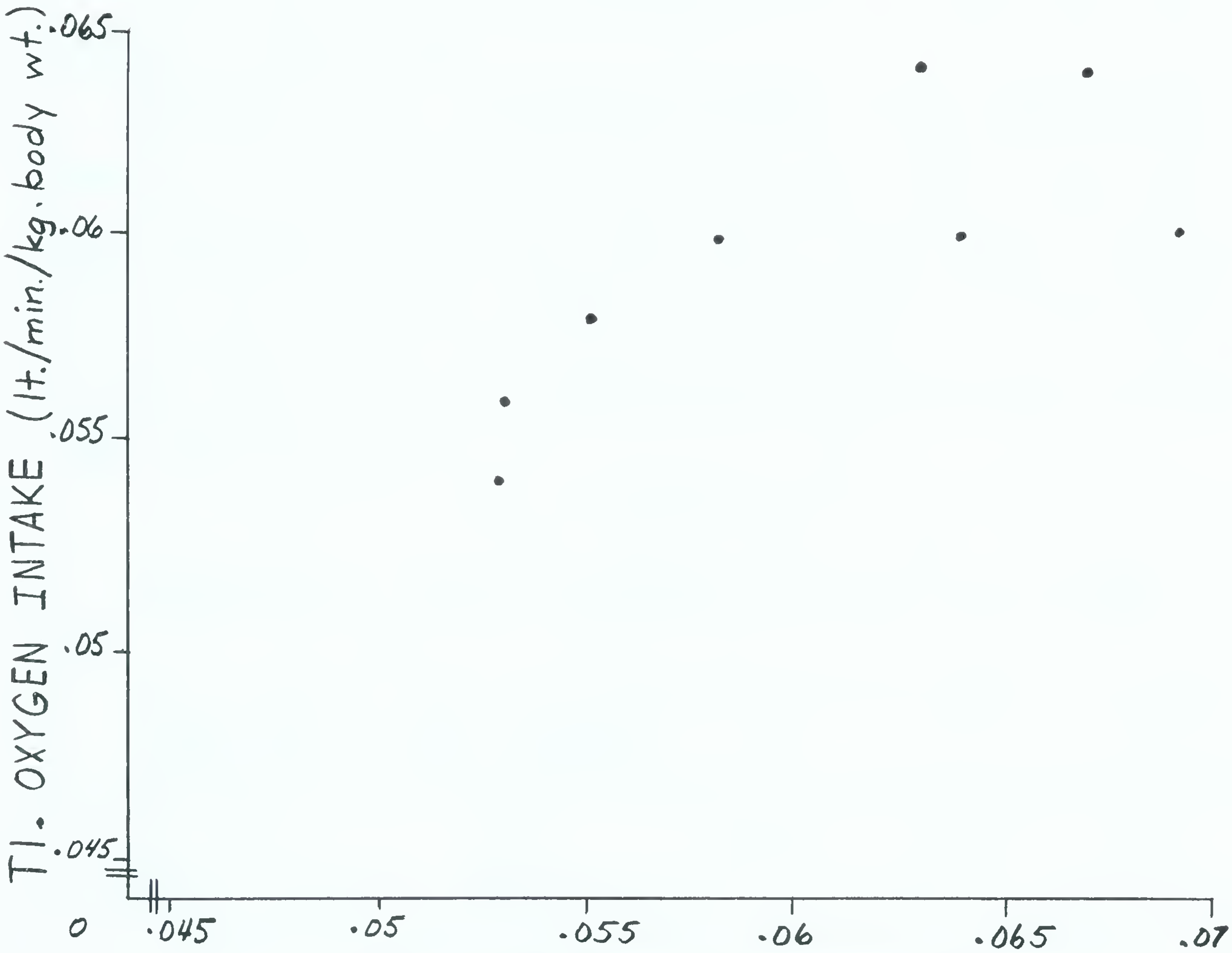


FIGURE 9 MAXIMAL OXYGEN INTAKE TESTS



T2. OXYGEN INTAKE (lt./min./kg. body wt.)

FIGURE 10 COMPARISON OF TREADMILL PERFORMANCE FOR TEST NO. 1 AND TEST NO. 2

which was found in test 1.

Subject 4 ran his maximal performance trials at the 2.5 percent grade rather than at the observed 0 percent grade. This change was implemented by the experimenter because this subject could run for at least 20 minutes at the 0 percent grade. The higher grade level decreased the running time.

Performance Time. The difference between the mean times for the maximal performance trials while breathing oxygen (oxygen trials) and while breathing air (air trials) was tested for significance. Table II shows the mean times, the variance of the difference between the pairs of observations (S_D^2), the unbiased estimate of the population variance ($S_{\bar{D}}^2$) and the *t* ratio.

TABLE II

Comparison Of Treadmill Performance Times With Air And Oxygen

Experimental Condition	Mean Performance Time (seconds)	S_D^2	$S_{\bar{D}}^2$	*t* ratio
Air Trials	242.9	17983.1	34.6	4.06*
Oxygen Trials	383.6			

* Statistically significant at the .001 level of confidence.

The mean performance times of the subjects running on air was 242.9 seconds, whereas that of the same subjects running on oxygen was 383.9 seconds. The mean difference of 140.7 seconds resulted in a *t* ratio of 4.06, which was statistically significant at the .001 level of confidence.

Heart Rate. The heart rates of each subject during rest (for one minute), during the maximal performance trial and during recovery (for 8 minutes) are cited in Appendix B. Two sample heart rates are shown in

figures 11 and 12 comparing the trials while breathing air and oxygen. The following may be observed from figures 11 and 12:

a) The breathing of high concentrations of oxygen did not appear to effect the level the heart rate reached at any particular point during the maximal performance trial.

b) Heart rates in the trials while breathing oxygen reached higher levels at the termination of the performance than those trials while breathing air, though performance time was significantly longer in the trials with oxygen.

c) The heart rates in the oxygen trials remained at steady state levels for longer periods of time than the air trials: for example, 5½ minutes, as shown in the May 23 test in figure 11.

d) The breathing of high concentrations of oxygen during the exercise period did not appear to effect the heart rate during the 8 minutes of recovery.

Oxygen Intake. A comparison of the oxygen intakes for the tests while breathing air and oxygen is shown in figure 13. The oxygen debts are shown in figure 14. The following may be observed from figures 13 and 14:

a) The oxygen intakes decreased during the recovery period. The values appeared to approach an asymptote.

b) The oxygen debt was lower in the first minute of recovery for the oxygen trials than for the air trials, despite the fact that the oxygen trials were significantly longer than the air trials.

c) After the first minute of recovery little difference was found for the oxygen intakes between the oxygen and air trials.

The difference between the mean oxygen debts found during the first minute of recovery for the oxygen trials and air trials was tested for

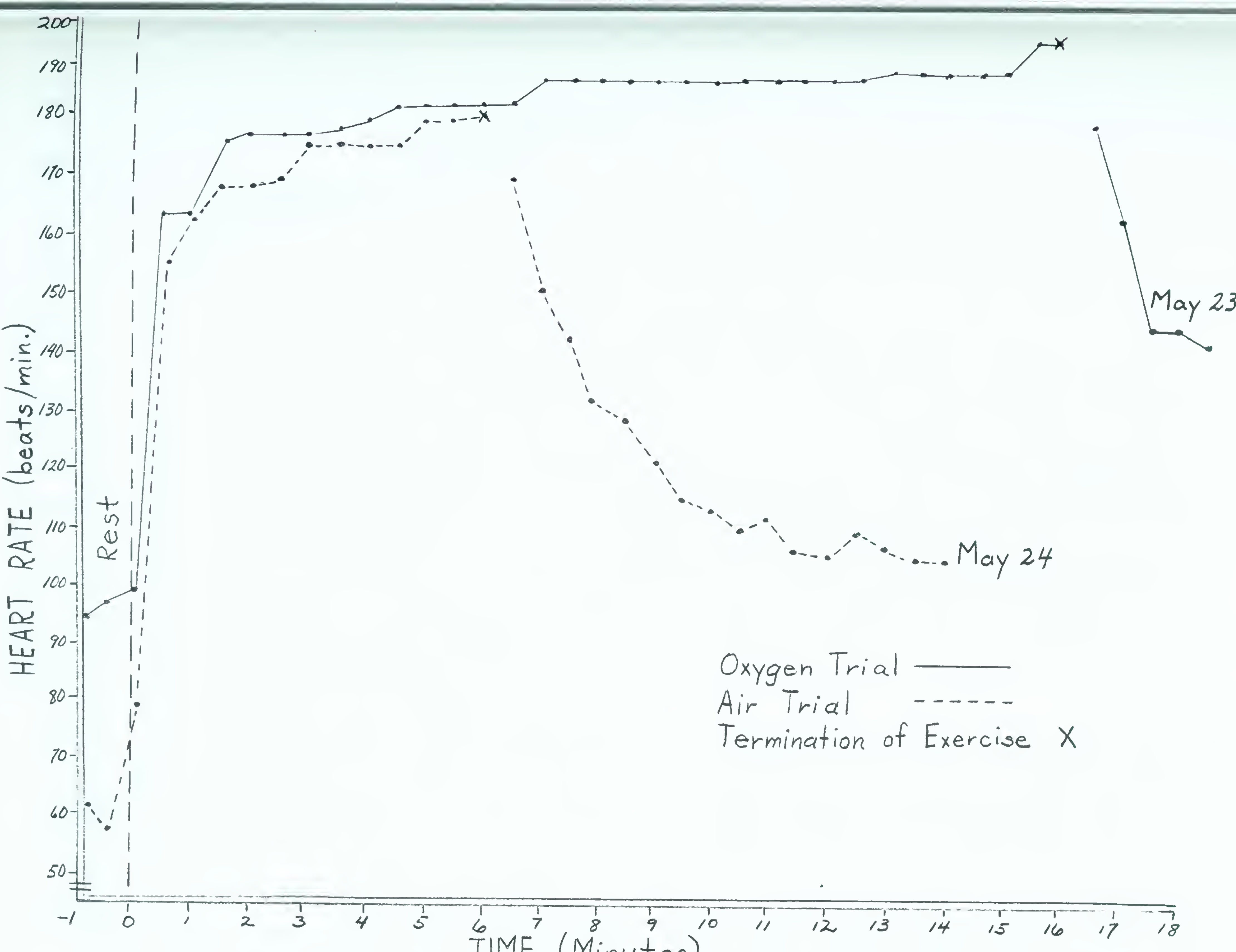


FIGURE 11 HEART RATE DURING REST, EXERCISE AND RECOVERY Subject No. 4

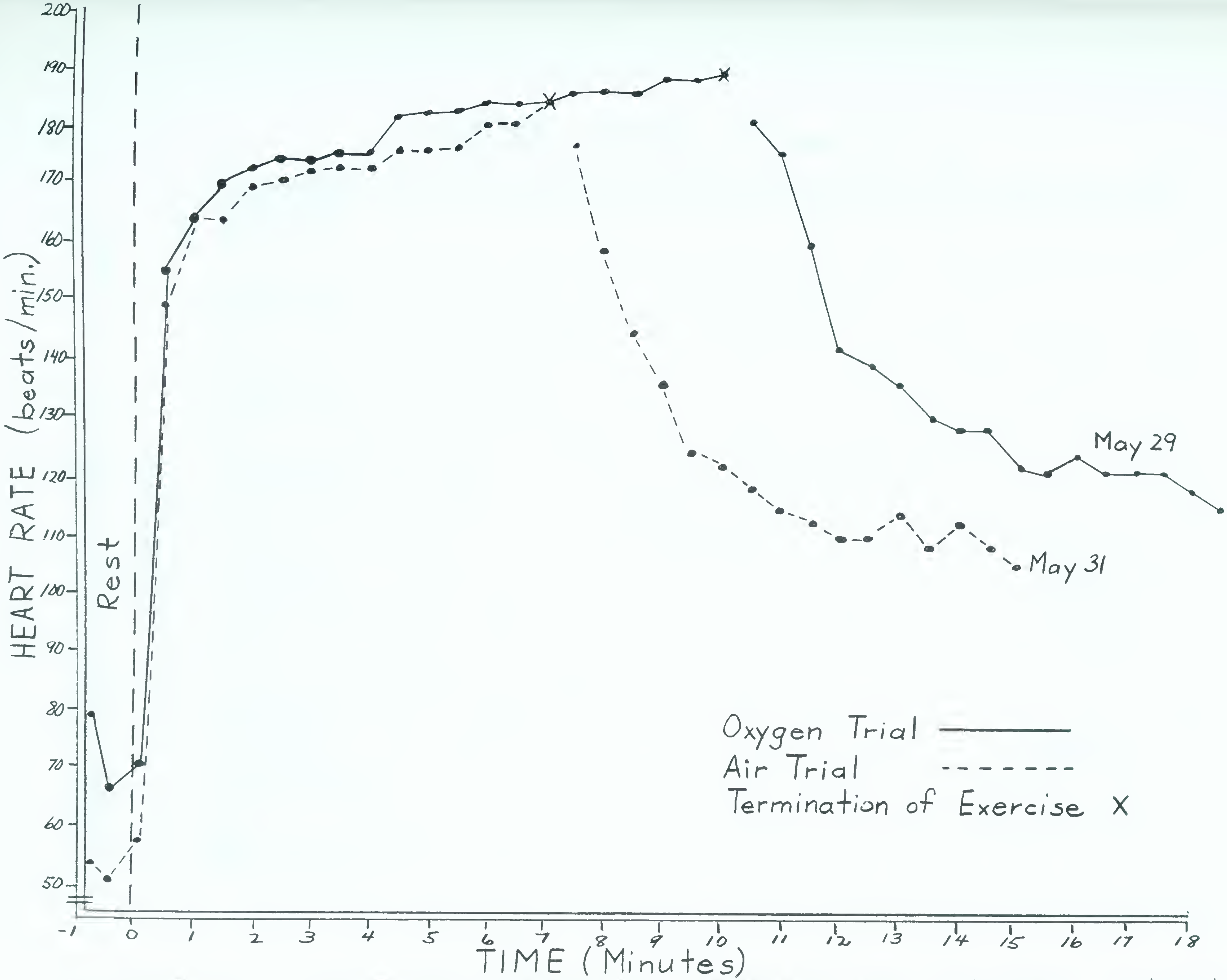


FIGURE 12 HEART RATE DURING REST, EXERCISE AND RECOVERY Subject No. 4

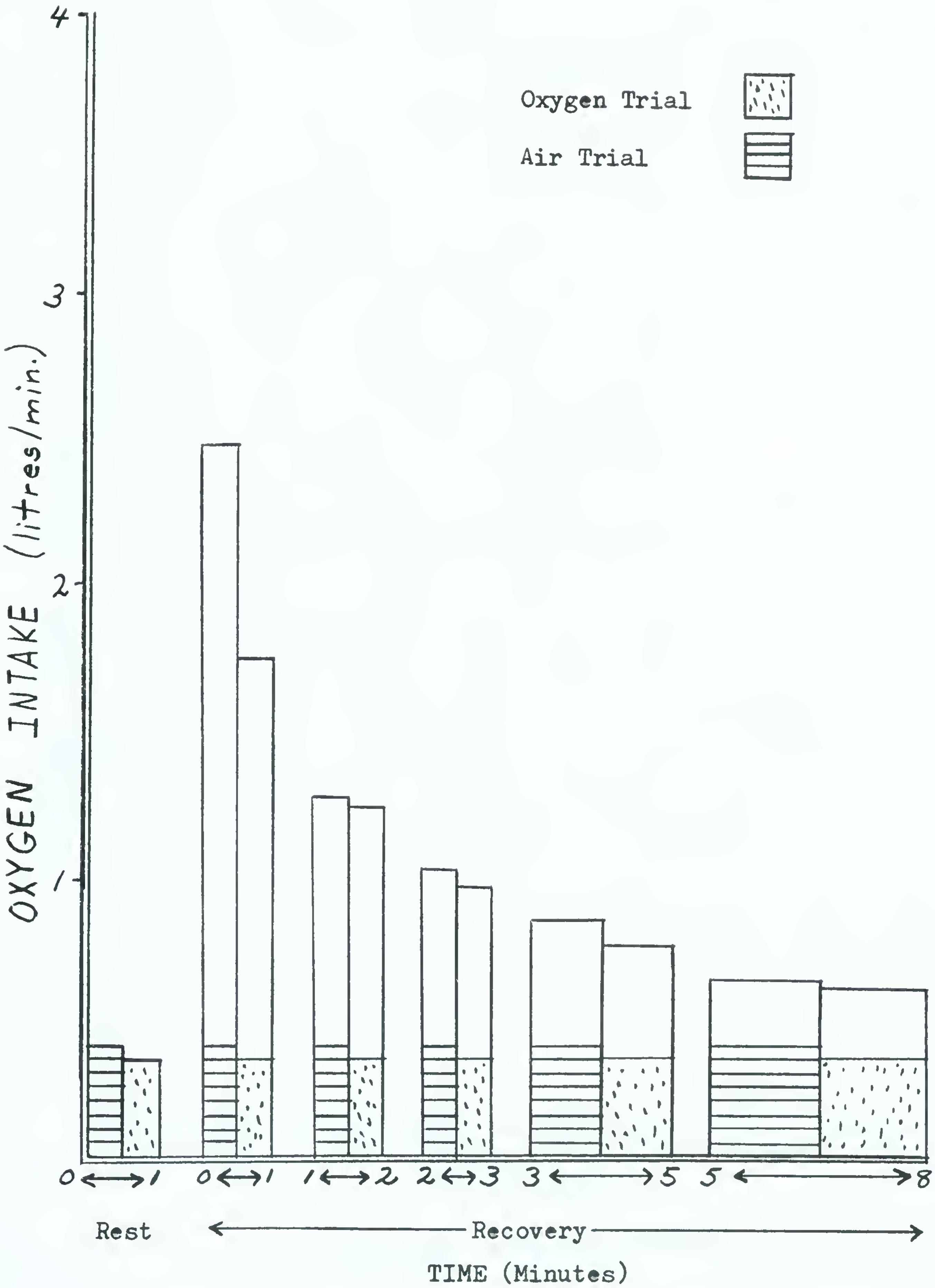


FIGURE 13 MEAN OXYGEN INTAKE FOR REST AND RECOVERY

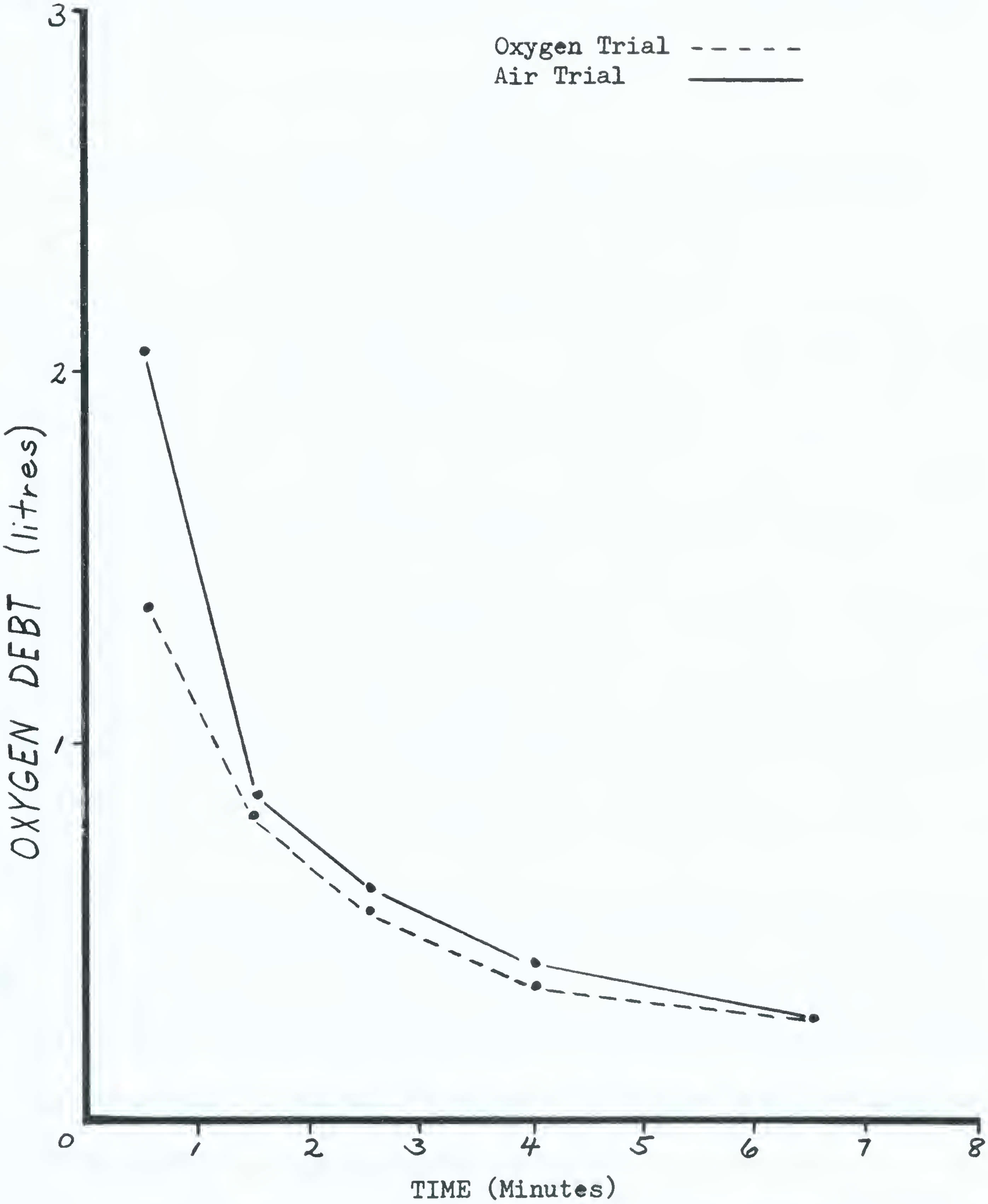


FIGURE 14 MEAN OXYGEN DEBT

significance. Table III shows the mean oxygen debts for the first minute of recovery, the variance of the difference between the pairs of observations (S_D^2), the unbiased estimate of the population variance ($S_{\bar{D}}^2$) and the t ratio.

TABLE III

Comparison Of Mean Oxygen Debt For Air And Oxygen Trials During The First Minute Of Recovery

Experimental Condition	Mean Oxygen Debt (litres)	S_D^2	$S_{\bar{D}}^2$	t ratio
Air Trials	2.097	.938	.063	2.58**
Oxygen Trials	1.388			

**Statistically significant at the .05 level of confidence.

The mean oxygen debt for the first minute of recovery of the subjects running on air was 2.097 litres, whereas that of the same subjects running on oxygen was 1.388 litres. The mean difference of .709 litres resulted in a t ratio of 2.58, which was statistically significant at the .05 level of confidence.

Lactic and Pyruvic Acid. Lactic acid accumulation for the pre-exercise sample and post-exercise sample is shown in figure 15. Recovery lactic acid levels above the pre-exercise level are shown in figure 16. Lactic acid (in mg percent) is plotted for each of the five samples taken during the recovery period. It may be observed that:

a) Lactic acid after air trials reached a peak lactic acid accumulation during the third minute of recovery.

b) Lactic acid after oxygen trials does not appear to reach a peak lactic acid accumulation during the 8 minutes of recovery.

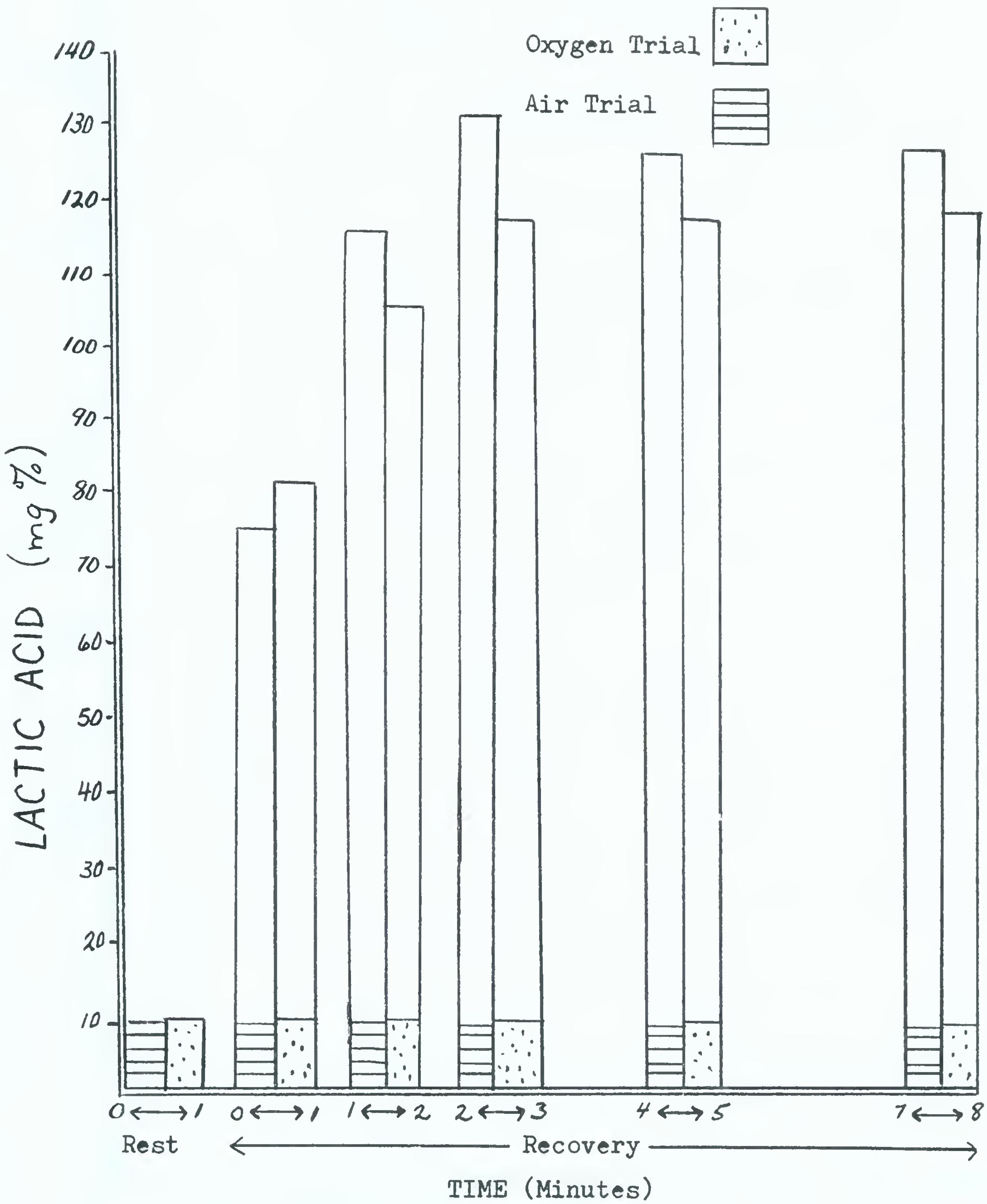


FIGURE 15 MEAN LACTIC ACID FOR REST AND RECOVERY

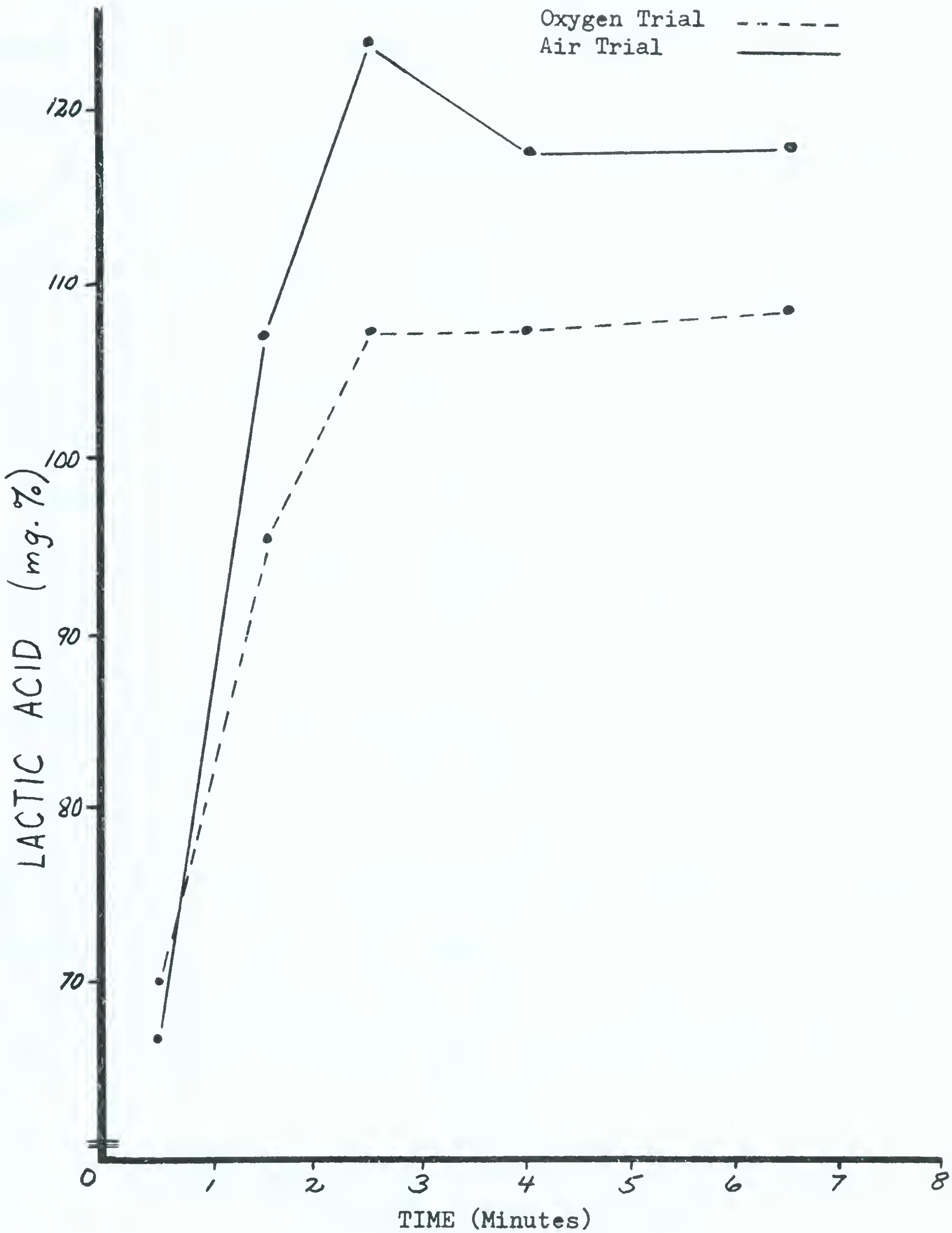


FIGURE 16 MEAN LACTIC ACID ABOVE THE PRE-EXERCISE LEVEL

c) The breathing of oxygen during the maximal performance trial reduced the lactic acid at each test period except the first minute after exercise.

Pyruvic acid accumulation for the pre-exercise and post-exercise samples is shown in figure 17. The breathing of oxygen during the maximal performance trials appeared to reduce the pyruvic acid accumulation for the first 3 minutes of recovery. No effect was observed by the breathing of oxygen on the accumulation of pyruvic acid from the third to eighth minutes of recovery.

Excess Lactic Acid. The excess lactic acid was plotted for the eight minutes of recovery for both the oxygen and air trials and is shown in figure 18. The following may be observed from this figure:

a) Excess lactic acid reached a peak value during the third minute of recovery for both the oxygen and air trials.

b) As compared to the excess lactic acid accumulation after air trials, the excess lactic acid after oxygen trials was reduced at each sample except the first. This is evident even though the performance time was significantly longer in the oxygen trials.

Table IV summarizes the comparison of the mean peak excess lactic acid at the third minute of recovery after the air and oxygen trials.

TABLE IV

The Peak Excess Lactic Acid For Air And Oxygen Trials

At The Third Minute Of Recovery

Experimental Condition	Mean Peak Excess Lactic Acid (mg%)	S_D^2	$S_{\bar{D}}^2$	t ratio
Air Trials	110.4			
Oxygen Trials	95.1	842.91	56.19	7.496*

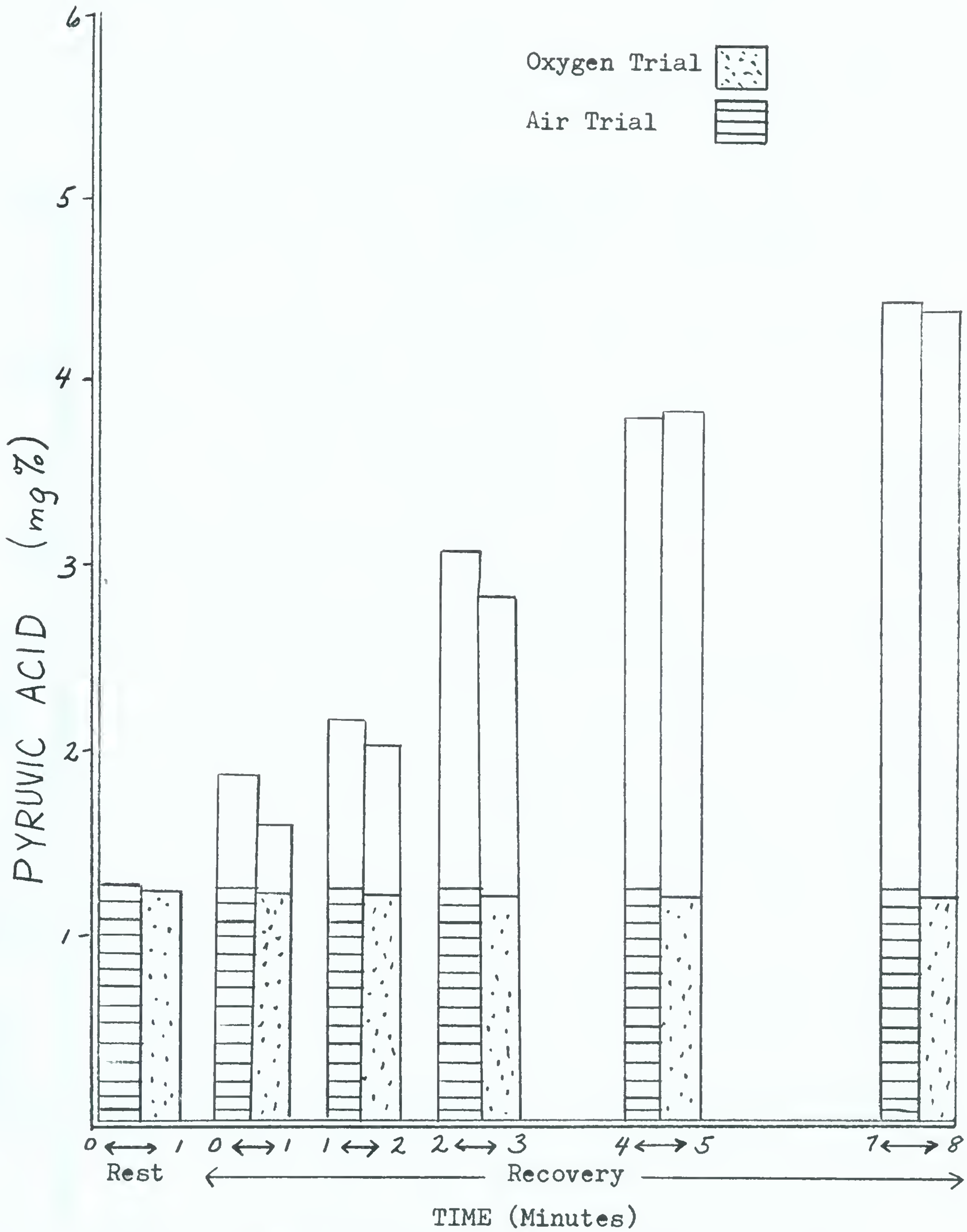


FIGURE 17 MEAN PYRUVIC ACID FOR REST AND RECOVERY

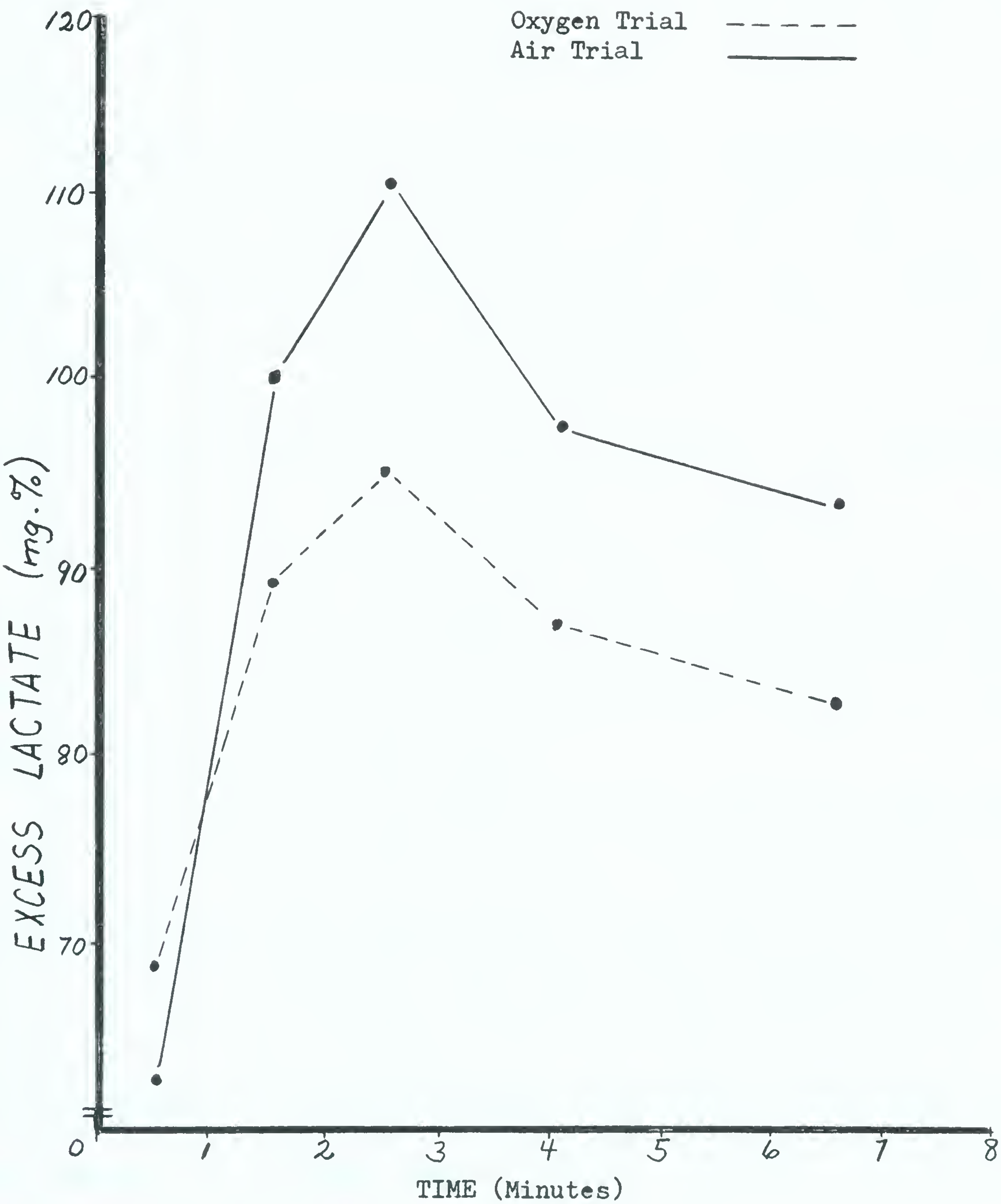


FIGURE 18 MEAN EXCESS LACTATE

*Statistically significant at the .001 level of confidence.

The mean peak excess lactic acid after the air trials was 110.4 mg percent, whereas the mean peak excess lactic acid after the oxygen trials was 95.1 mg percent. The mean difference of 15.3 mg percent resulted in a $\underline{t}$ ratio of 7.496, which was statistically significant at the .001 level of confidence.

Oxygen Debt and Lactic Acid. A comparison of the mean lactic acid and the mean oxygen debt is shown in figure 19. The comparison was made after the peak was reached at 3 minutes to the end of recovery at 8 minutes. A similar comparison between the oxygen debt and excess lactic acid is shown in figure 20. There appeared to be no relationship between the mean lactic acid and the mean oxygen debt, whereas there appeared to be a relationship between the mean excess lactic acid and the mean oxygen debt.

There was no alteration in the relationship found between oxygen debt and excess lactic acid or in the lack of relationship found between oxygen debt and lactic acid as a result of breathing high concentrations of oxygen during the maximal performance trials.

Figure 21 shows the relationship between the cumulative oxygen debt and the cumulative excess lactic acid over the 8 minutes of recovery. The effect of breathing high concentrations of oxygen was to shift the line curve to the left in the graph. The effect was very slight after the initial phase of recovery and the lines tend to parallel each other throughout the remainder of the recovery period. The line of relationship tends to be lowered as the recovery period proceeds. The effect was most obvious in the last 5 minutes of recovery.

It was also observed that as the cumulative oxygen debt increased the cumulative excess lactic acid increased to a greater extent.

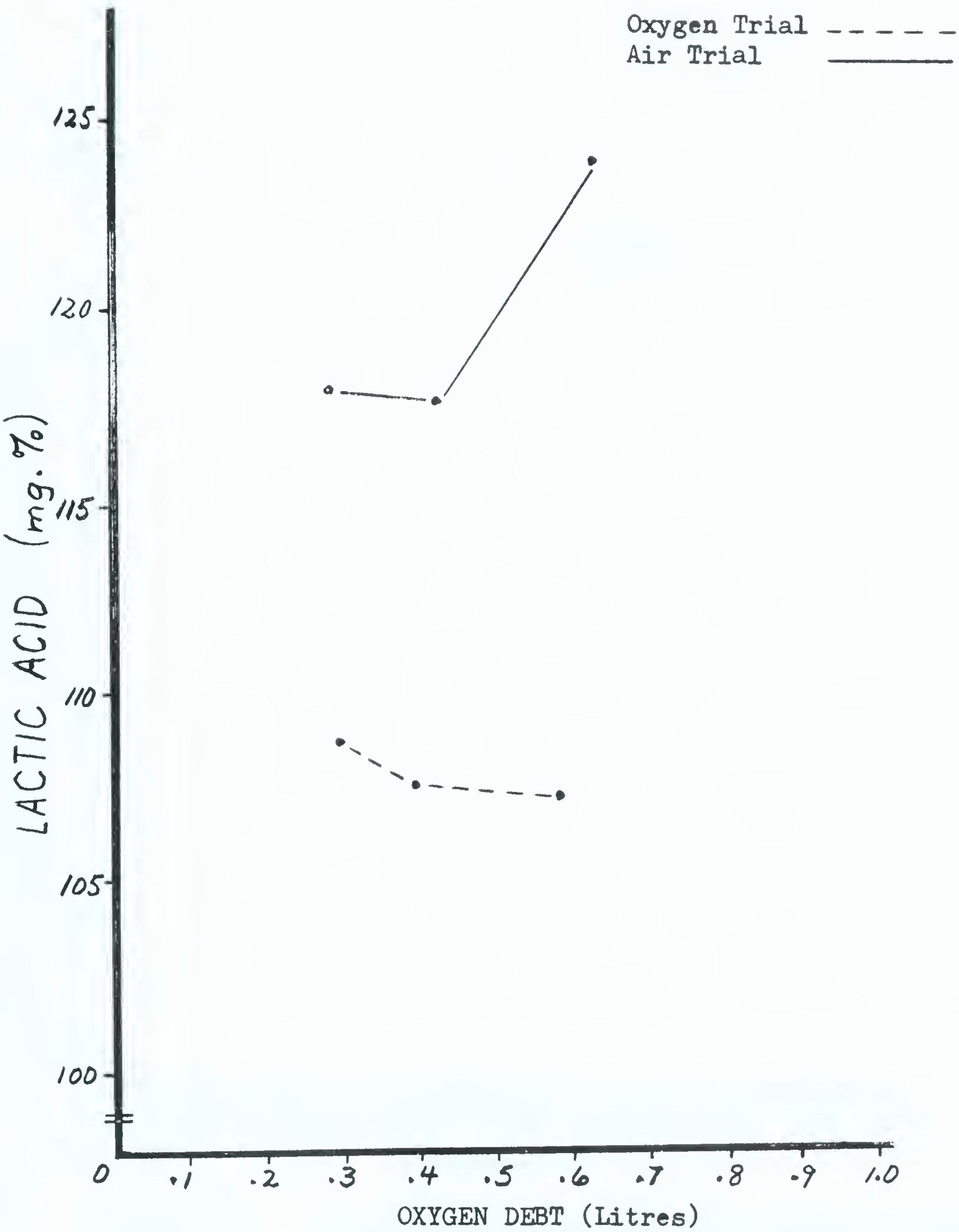


FIGURE 19 RELATIONSHIP BETWEEN MEAN OXYGEN DEBT AND MEAN LACTIC ACID FOR THE THIRD TO EIGHTH MINUTE OF RECOVERY

[illegible]

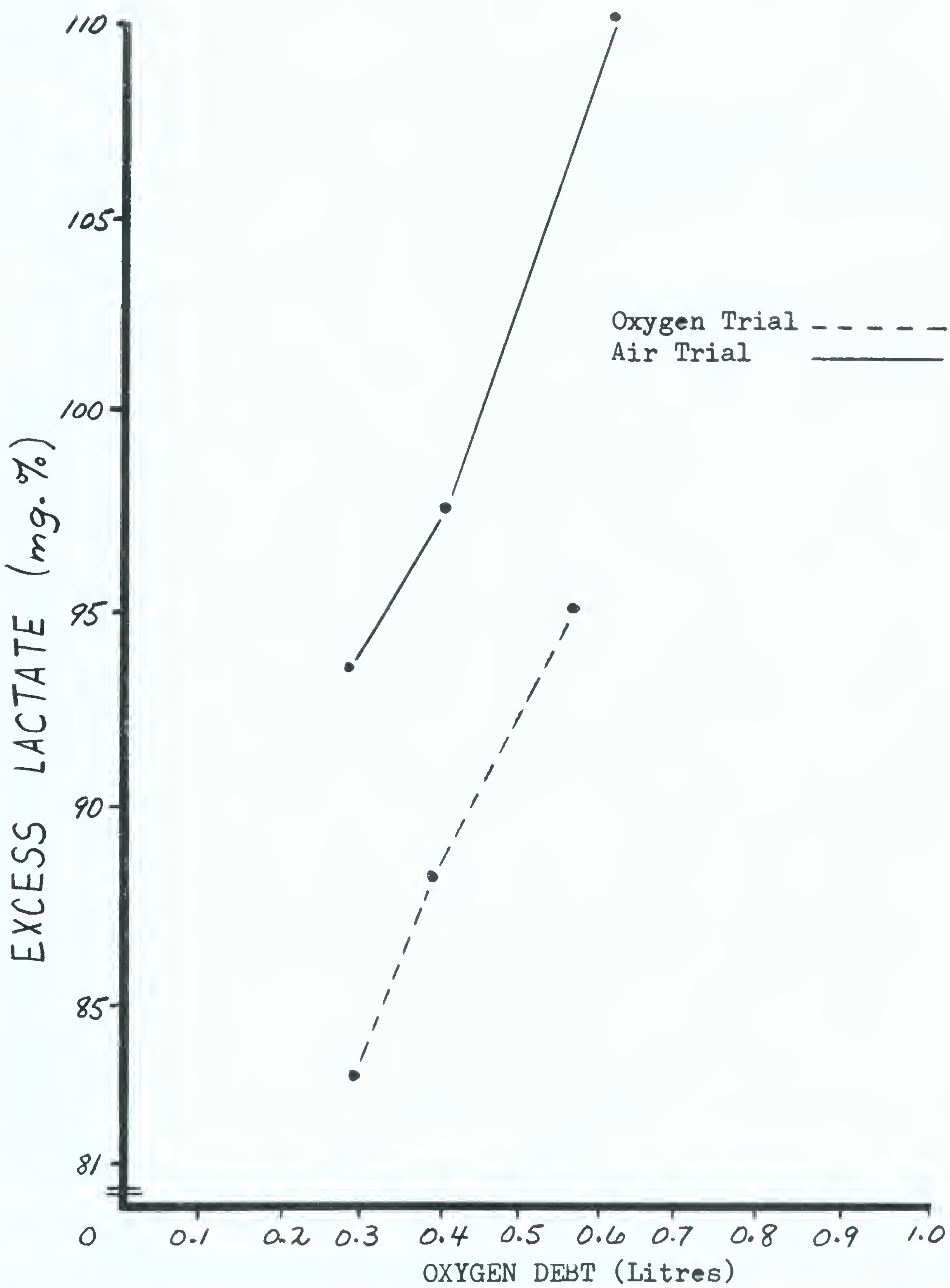


FIGURE 20 RELATIONSHIP BETWEEN MEAN OXYGEN DEBT AND MEAN EXCESS LACTIC ACID FOR THE THIRD TO EIGHTH MINUTE OF RECOVERY

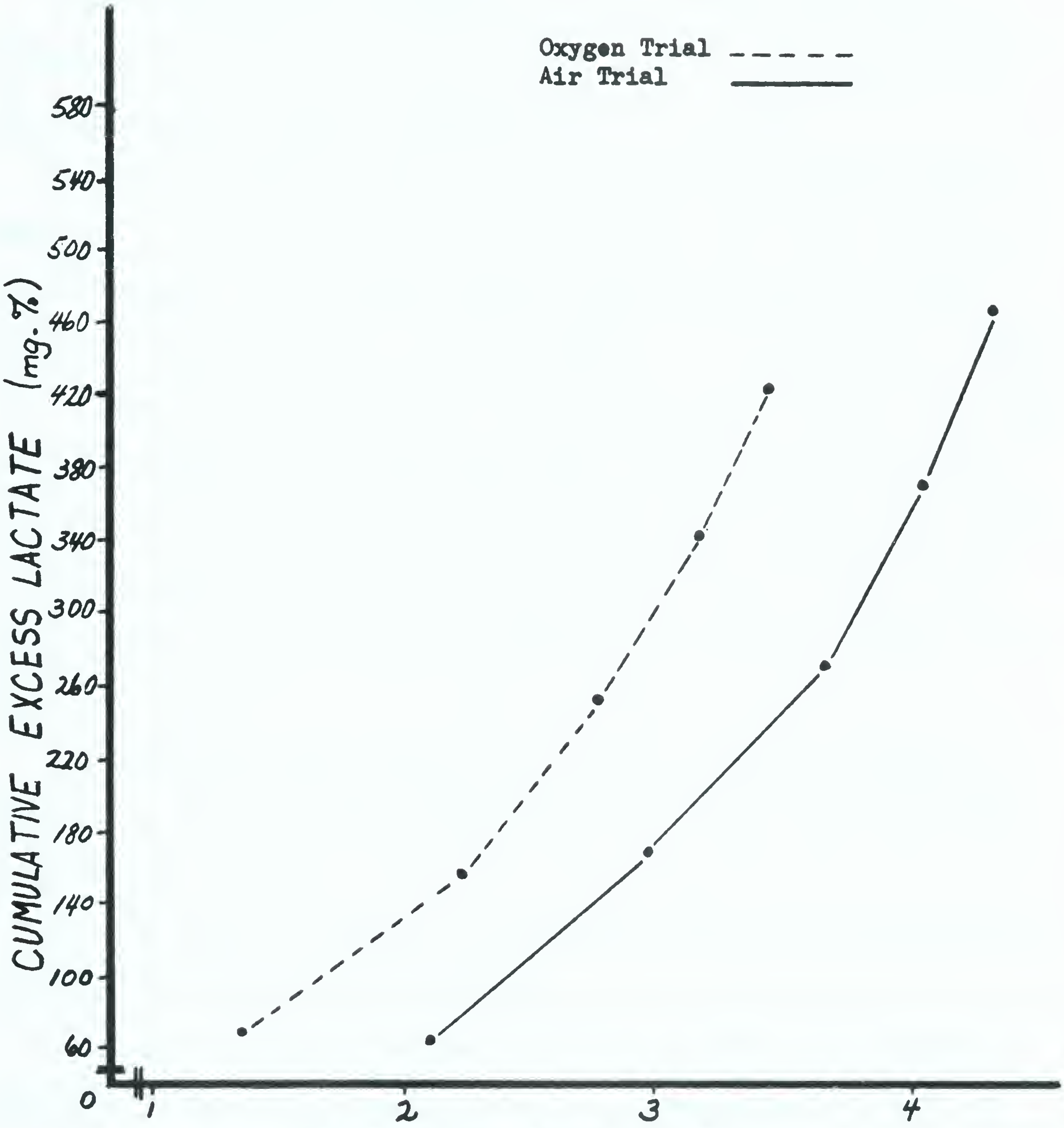


FIGURE 21 RELATIONSHIP BETWEEN CUMULATIVE EXCESS LACTATE AND CUMULATIVE OXYGEN DEBT

Discussion

In the discussion of the results, it must be kept in mind that each maximal performance trial was different in time. The oxygen trials were significantly longer in duration than the air trials.

As stated by Margaria, et. al. (1), the increased treadmill performance time in their experiment was due to an increased oxygen consumption of $\pm$ 1.2 percent. The increased oxygen consumption during the oxygen trials was supported by Hill, Long and Lupton (2) and Clark-Kennedy, et. al. (3). Although the tests performed by Margaria, et. al. (1), were run using 100 percent oxygen, Nahas, Morgan and Wood (4), point out that complete saturation of arterial blood was found with 70 percent oxygen in nitrogen. It may be reasoned, therefore, that an increased oxygen consumption of similar magnitude would be found in tests run on 70 percent oxygen, as in the present study.

The increased oxygen uptake by the blood is outlined by Margaria, et. al. (1). They state that oxygen consumption ($\dot{V}O_2$) can be expressed by the formula:

$\dot{V}O_2 = g.f.\Delta O_2$, where: g. = the stroke volume; f. = the heart rate and ΔO_2 = the arteriovenous difference.

Based on the theory by Rushmer (as cited in 1:466), the changes in the cardiac output during exercise are due to changes in the heart rate and not to the stroke volume. Oxygen inhalation appeared to have no effect on heart rate during maximal performance trials. This observation is supported by Asmussen, et. al. (5), Miller (6) and Asmussen and Nielsen (7). From these two assumptions it is evident that the product of g.f. is not influenced by oxygen changes in the inspired air. The increased oxygen

consumption during the oxygen trials would, therefore, be due to increased oxygen physically dissolved in the blood or due to the increased chemical combination between the oxygen and the hemoglobin of the blood. Bard (8:597) states that as the oxygen tension of the inspired air increases over the normal levels, little change occurs in the volume of the oxygen held by the hemoglobin. This is illustrated by the flat upper position of the dissociation curve. The increased oxygen consumption is carried, therefore, in physical solution in the blood and is not due to a higher saturation of the hemoglobin or a faster blood circulation.

The increased mean performance time for the oxygen trials may be due to two factors: 1) The increased delivery of oxygen to the cardiac muscles would increase the efficiency of the cardiac muscle. The resulting increase in cardiac output would permit a greater quantity of oxygen to be carried to the working muscles. 2) Several authors (3,16,19,20), have shown that the ventilatory volume is decreased during performance while breathing high concentrations of oxygen. This may also be concluded from the decreased oxygen debt for the first minute of recovery found in this experiment. A decrease in ventilatory volume would relieve the feeling of dyspnea especially in the unnatural situation of breathing through a two-way valve. The relief of dyspnea would result in an increased performance time.

The breathing of oxygen during the maximal performance trials does not appear to effect the course of the heart rate <u>during recovery</u>. This observation is not directly stated by the authors reviewed but several (2,6,7, 9,10) imply that no change was found in recovery heart rate. Miyama (11), however, found a faster return of the heart rate to normal values when breathing oxygen during the recovery period.

<u>Oxygen Debt and Lactic Acid</u>. The significant decrease in oxygen debt during the first minute of recovery despite the increased performance of the oxygen trials was due to the increased availability of oxygen during the oxygen trials. This observation was connected with the changes that take place in the contracting muscles and their requirements for performing the maximal exercise. Muscular contraction involves the use of stores of fuel, which are oxidized in the process of releasing energy (12). Because oxygen stores in the blood are minimal, oxygen must be continuously supplied to the cells by the blood. During exercise, the breakdown of energy-rich compounds such as creatine phosphate is highly accelerated. The oxidative machinery, the Krebs cycle, resynthesizes the creatine phosphate. This is done very effectively as long as the oxygen supply is adequate. As the oxygen supply becomes less adequate and the anaerobic work increases, lactic acid is formed.

Since there was a decrease in the oxygen debt and lactic acid in the oxygen trials, there was, therefore, a decrease in the anaerobic work performed in the oxygen trials.

As stated by Huckabee (13), part of the lactic acid formed during exercise is due to the pyruvic acid present in the blood. The excess lactic acid (lactic acid minus the pyruvic equivalent of lactic acid) formed during the oxygen trials was significantly lower than the quantity formed during the air trials. This is due to a decrease in the amount of anaerobic work performed even though the oxygen runs were longer.

The decreased lactic acid found during the oxygen trials as compared with that found during the air trials was supported by many authors (6,14, 15,16,17).

Lactic acid and oxygen debt have often been referred to as an indication of fatigue. Christensen (as cited in 18:310), states that it (lactic acid) " . . . is only an indication that when you reach this level you know you can't go on." The results of this study do not support this statement. Fatigue occurs in the oxygen trials when lower oxygen debt and excess lactic acid levels are reached. If lactic acid and oxygen debt were the factors determining fatigue, no difference between the mean oxygen debt and excess lactic acid for the oxygen and air trials would have been found. Theoretically the mean performance time for oxygen trials would be much greater than that observed since the oxygen debt or lactic acid levels of the air trials had not been reached. As Bard (8) states, the subjective experience of fatigue is a complex response to a variety of conditions, among which are an emotional state, difficult breathing, insufficient cardiovascular adjustments and mechanical fatigue such as lactic acid accumulation.

The appearance of a peak value in the excess lactic acid accumulation during the third minute of recovery is supported by Brouha, et. al. (as cited in 12:181). "When exercise stops lactate continues to escape from the muscles for a few minutes and its blood concentration increases." As the oxygen is again made available the excess lactic acid is reconverted to glycogen by the liver and then there appears a decrease in excess lactic acid after the third minute of recovery.

Pyruvic acid accumulation under the two conditions of breathing air and oxygen is not mentioned by the authors reviewed. It appears to be effected very little by the concentrations of the oxygen in the inspired air. This is understandable since pyruvic acid is a product of aerobic metabolism.

The relationship between oxygen debt and excess lactic acid and the effect on this relationship due to breathing high concentrations of oxygen were outlined in the results. The evidence of Huckabee (13) showed that the intravenous infusion of pyruvate produced major changes in the concentration of lactate without effecting oxygen consumption. As previously mentioned the ventilatory volume is decreased in the oxygen trials. According to Huckabee (13) lactate production theoretically is not controlled by the adequacy of cellular oxygenation and will vary considerably with the pH alteration which is raised by the hyperventilation. As Huckabee (13:252) concludes, the " . . . production by tissues in intact man and animals has no necessary significance with respect to hypoxia of the tissues." Excess lactic acid is therefore reported to have a higher relationship with oxygen debt than lactic acid. This has been further substantiated by the results of this experiment.

The relationship is not changed by breathing high concentrations of oxygen although the line of relation is lowered on the graph. There is not a one to one relationship between the oxygen debt and excess lactic acid but rather greater quantities of excess lactic acid are formed in relation to the oxygen debt.

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CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the effects of breathing high concentrations of oxygen (70-73 percent in nitrogen) on treadmill performance and on the exercise and post-exercise pulse rate and the relationship between excess lactic acid production and oxygen debt.

Seven relatively fit students and faculty members of the University of Alberta served as subjects for this experiment. The subjects participated in repeated tests for both the oxygen and air trials. Each subject underwent a preliminary maximal oxygen intake test to determine the treadmill grade at which he reached his maximal oxygen intake. The subsequent maximal performance trials were run at this pre-determined treadmill grade.

During each maximal performance trial the following information was recorded: time to reach exhaustion; pre-exercise, exercise and post-exercise heart rate; pre-exercise and post-exercise oxygen intake; and lactic and pyruvic acid levels.

The following conclusions appear to be justified within the delimitations as previously outlined:

1. The breathing of 70-73 percent oxygen in nitrogen during a maximal treadmill performance trial significantly increased the treadmill performance time.

2. The breathing of 70-73 percent oxygen in nitrogen during a maximal treadmill performance trial significantly reduced the oxygen debt during the first minute of recovery despite the fact that the performance time was longer for the oxygen trials. There was no effect on the oxygen debt after the first minute of recovery.

3. The breathing of 70-73 percent oxygen in nitrogen appeared to reduce the level of lactic acid after the first minute of recovery.

4. The breathing of 70-73 percent oxygen in nitrogen did not appear to effect the pyruvic acid level during the first eight minutes of recovery.

5. The breathing of 70-73 percent oxygen in nitrogen during a maximal treadmill performance trial significantly reduced the excess lactic acid level, despite the fact that the subjects performed longer on the oxygen trials.

6. The excess lactic acid reached a peak value during the third minute of recovery.

7. There appeared to be a relationship between oxygen debt and excess lactic acid but not between oxygen debt and lactic acid for the third to eighth minute of recovery.

8. The relationship between cumulative oxygen debt and cumulative excess lactic acid showed a disproportionately greater rise in excess lactic acid in relation to oxygen debt.

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APPENDIX A

STATISTICAL TREATMENT

The significance of the difference between the means for the air and oxygen trials for: (1) the mean performance time, (2) the oxygen debt during the first minute of recovery, and (3) the excess lactic acid during the third minute of recovery was calculated according to the method as outlined by Ferguson (1:138).

Significance of the Difference Between Two Means For Correlated Samples.

(1) The Variance of the Difference Between the Paired Observations:

$$S_D^2 = \frac{\Sigma D^2}{N} - \bar{D}^2$$

(2) The Unbiased Estimate of the Population Variance:

$$S_{\bar{D}}^2 = \frac{S_D^2}{N-1}$$

(3) _t_ ratio:

$$t = \frac{\bar{D}}{S_{\bar{D}}} = \frac{\bar{D}}{\sqrt{S_D^2 / (N-1)}}$$

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APPENDIX B

MAXIMAL OXYGEN INTAKE

SUBJECT	TEST I		TEST II		
	lt/min	lt/min/kg body wt	lt/min	lt/min/kg body wt	Grade Level Used (percent)
1	4.901	.058	4.999	.060	5
2	4.213	.056	4.02	.053	2.5
3	3.94	.060	4.347	.064	2.5
4	3.132	.047	-	-	2.5
5	3.817	.046	-	-	2.5
6	3.878	.060	4.421	.069	7.5
7	3.994	.058	3.736	.055	2.5
8	4.574	.064	4.851	.067	-
9	4.622	.063	4.681	.064	-
10	4.009	.054	3.810	.053	-

TREADMILL PERFORMANCE TIMES
(in seconds)

SUBJECT	TRIAL NUMBER	AIR	TRIAL NUMBER	OXYGEN
1	2	335	1	483
2	1	234	2	475
	3	222	4	320
	5	192	6	226
3	2	320	1	412
	4	223	3	410
	6	234	5	332
4	2	364	1	963
	4	432	3	601
5	1	213	2	186
6	1	199	2	324
	3	182	4	297
	5	229	6	362
7	2	168	1	200
	4	186	3	247
	6	154	5	300
TOTAL		3887		6138
MEAN		242.9		383.6

HEART RATE
FOR PRE-EXERCISE, EXERCISE AND RECOVERY

Subject	Trial	Pre-Exercise	Heart Rate (Beats per minute recorded every 30 seconds) Exercise and Recovery
1	1	62 65 76	150 155 161 167 167 173 173 173 173 173 176 180 180 180 180 187 170 155 141 132 121 122 120 118 118 118 115 114 110 115 115
	2	80 85 83	161 163 163 170 173 173 177 178 180 180 180 161 145 118 115 110 107 113 105 105 103 107 107 107 107 105 108
2	1	96 95 90	158 167 170 173 173 180 180 167 161 155 145 132 129 125 121 122 122 118 115 115 115
	2	90 87 96	141 150 161 167 173 175 175 180 167 167 147 134 134 134 129 122 125 123 122 118 122 115 122 122 125
	3	83 70 82	141 155 164 164 169 175 175 164 141 130 125 118 114 110 110 114 113 111 109 113 107 113 110
	4	104 83105	141 152 161 167 173 176 176 180 180 180 164 152 141 132 123 122 123 115 115 114 114 114 116 112 118
	5	79 94 89	145 158 164 167 173 173 155 142 129 117 107 106 103 110 110 103 104 103 100 104 100 105
	6	67 83 75	143 150 155 164 164 173 176 173 155 145 132 127 120 117 110 107 106 113 107 111 105 110 107

Subject	Trial	Heart Rate (Beats per minute recorded every 30 seconds) Pre-Exercise	 Exercise and Recovery
3	1	97 72 96	145 150 152 155 161 164 165 166 168 173 173 173 176 167 153 141 127 125 120 118 114 115 112 113 113 112 110 112 113
	2	57 75 78	139 141 150 150 153 155 160 161 161 167 155 145 134 132 120 115 114 118 112 107 107 115 110 107 105 107 110
	3	70 65 63	135 142 145 152 158 161 161 161 167 170 173 173 173 167 150 134 129 115 110 109 111 104 100 104 109 103 102 106 103
	4	60 66 72	134 143 145 150 153 158 164 164 145 130 127 115 104 105 104 95 93 96 96 94 96 94 96
	5	88 85 83	141 150 155 161 161 167 170 170 173 177 179 161 150 136 123 122 120 113 114 112 114 112 110 107 107 106 114
	6	68 69 66	143 155 157 164 167 167 167 148 136 130 125 122 113 112 110 108 106 104 110
4	1	94 96 98	164 164 176 177 177 177 179 180 183 183 183 183 183 187 187 187 187 187 187 187 187 187 187 187 187 189 189 189 189 189 195 195 180 164 145 145 143 142 142 132 136 132 130 132 132 125 123 127
	2	62 57 78	155 163 167 167 170 176 176 176 176 180 180 182 170 152 143 132 129 122 115 114 110 113 106 106 110 107 105 105
	3	80 67 72	155 164 170 173 174 174 175 175 182 183 183 184 184 184 185 185 185 187 187 189 180 175 158 141 139 136 130 129 129 123 122 124 122 122 122 118 115
	4	54 52 58	149 164 164 169 170 173 173 173 175 175 176 180 180 184 176 158 145 136 124 123 118 115 113 110 110 114 109 113 108 105

Subject	Trial	Heart Rate (Beats per minute recorded every 30 seconds)																					
		Pre-Exercise			Exercise and Recovery																		
5	1	73	74	73	158	167	170	173	173	176	176	170	161	158	147	143	141	141	134	134	130	127	127
					124	122	120																
	2	79	87	89	158	161	169	173	175	179	179	170	165	158	150	148	143	141	136	136	130	127	127
					125	123	122																
6	1	68	70	82	140	141	150	155	162	170	167	166	150	141	127	117	112	109	105	104	103	105	105
					107	105	110	112															
	2	73	67	61	141	150	155	160	161	161	164	167	170	170	168	152	141	130	122	114	114	112	107
					112	114	110	109	113	114	113												
	3	70	70	73	143	145	153	160	164	173	155	141	122	112	104	106	104	105	97	103	96	100	107
					107	106	106																
	4	61	56	64	142	146	161	167	170	170	171	173	175	174	160	147	128	120	117	110	106	106	105
					105	107	105	105	108	104	108												
	5	58	67	78	150	152	155	162	165	166	159	150	135	120	114	109	106	105	100	104	100	102	98
					95	99	97																
	6	73	56	67	144	148	157	166	166	170	170	171	172	173	173	175	157	145	127	116	113	112	104
					100	105	105	103	103	99	105	109											

Heart Rate (Beats per minute recorded every 30 seconds)

Subject	Trial	Pre-Exercise			Exercise and Recovery																		
7	1	88	79	103	145	147	158	164	170	173	170	157	145	132	125	113	113	110	113	112	112	110	109
					107	106	107	115															
	2	98	92	98	143	158	164	170	173	155	141	129	141	122	117	132	117	113	112	113	106	113	110
					110	113	117																
	3	108	100	105	145	152	157	162	168	172	179	179	157	145	133	122	118	113	111	109	108	106	104
					100	99	99	103	107														
	4	96	91	94	144	150	159	161	165	171	170	155	139	127	120	117	106	112	104	106	102	104	103
					103	104	98	97															
	5	83	95	95	136	150	155	156	163	164	170	170	171	179	150	136	124	115	113	110	106	106	104
					104	104	103	95	95	101	101												
	6	84	83	83	144	149	160	166	173	144	140	126	117	105	102	103	104	96	98	98	96	99	96
					92	89																	

OXYGEN INTAKE
(in litres/minute)

SUBJECT	TRIAL NUMBER	AFTER BREATHING AIR OR OXYGEN	OXYGEN INTAKE					
			pre-exercise	post-exercise samples 1	2	3	4	5
1	1	oxygen	.542	2.563	1.474	1.131	1.078	.906
	2	air	.467	3.605	1.507	1.410	1.005	.877
2	1	air	.661	2.272	1.506	1.025	.692	-
	2	oxygen	.564	1.491	1.072	.812	.744	.627
	3	air	.448	2.341	1.045	.846	.638	.540
	4	oxygen	.409	2.008	1.053	0.927	.746	.651
	5	air	.429	2.581	1.202	.929	.746	.630
	6	oxygen	.417	2.587	1.127	.900	.738	.644
3	1	oxygen	.527	1.801	1.033	.985	.790	.758
	2	air	.443	2.758	1.318	.990	.814	.732
	3	oxygen	.337	1.600	1.414	.902	.792	.734
	4	air	.329	2.533	1.335	.934	.773	.615
	5	oxygen	.309	1.553	1.057	.859	.617	.572
	6	air	.312	2.507	1.302	1.051	.826	.673
4	1	oxygen	.394	1.098	1.044	.827	.742	.635
	2	air	.393	2.143	1.064	.881	.742	.614
	3	oxygen	.390	1.548	1.151	1.086	.696	.593
	4	air	.368	2.249	1.040	.910	.726	.578
5	1	air	.452	2.204	1.415	1.185	.974	.718
	2	oxygen	.357	1.513	1.227	.970	.784	.641
	3	air	.471	2.576	1.412	1.070	.912	.723
6	1	air	.333	2.163	1.201	.971	.822	.670
	2	oxygen	.267	1.563	1.286	1.035	.846	.708
	3	air	.280	2.511	1.242	1.069	.909	.712
	4	oxygen	.289	1.410	1.305	1.000	.820	.659
	5	air	.302	2.401	1.425	1.024	.840	.674
	6	oxygen	.290	1.452	1.242	.908	.770	.654
7	1	oxygen	.295	1.717	1.249	.852	.642	.579
	2	air	.348	2.505	1.353	1.024	.764	.649
	3	oxygen	.422	2.200	1.349	.990	.806	.673
	4	air	.498	2.638	1.517	1.155	.925	.706
	5	oxygen	.430	2.349	1.413	1.015	.828	.700
	6	air	.423	2.616	1.201	.941	.752	.587

LACTIC ACID
(mg %)

SUBJECT	TRIAL NUMBER	AFTER BREATHING AIR OR OXYGEN	LACTIC ACID					
			pre-exercise	post-exercise samples 1	2	3	4	5
1	1	oxygen	6.7	95.3	98.0	90.2	111.4	118.4
	2	air	6.11	-	-	121.4	92.3	122.1
2	1	air	8.5	76.4	73.8	83.1	84.7	-
	2	oxygen	4.8	47.3	91.6	88.2	127.0	142.1
	3	air	6.4	41.3	90.5	127.8	94.9	126.9
	4	oxygen	7.0	47.1	100.2	112.7	90.6	117.3
	5	air	8.7	52.1	89.1	89.9	98.8	113.1
	6	oxygen	13.2	50.5	79.4	110.4	108.5	108.5
3	1	oxygen	4.9	39.1	46.4	132.4	89.1	-
	2	air	10.9	92.1	123.0	162.4	122.1	125.2
	3	oxygen	11.1	99.2	96.3	107.6	107.9	98.0
	4	air	9.2	55.3	98.1	107.7	110.3	95.2
	5	oxygen	8.8	63.6	87.4	49.8	90.1	71.5
	6	air	5.7	55.2	104.9	133.1	119.8	106.3
4	1	oxygen	13.0	92.7	94.0	94.7	65.1	58.6
	2	air	6.0	88.4	119.6	124.9	132.8	133.7
	3	oxygen	9.5	126.4	138.2	148.6	150.0	152.9
	4	air	7.6	138.0	148.9	150.1	130.2	124.9
5	1	air	10.5	70.6	117.4	147.5	155.5	173.3
	2	oxygen	10.4	44.3	70.8	113.8	119.5	132.0
6	1	air	13.3	117.5	171.4	184.8	194.7	153.8
	2	oxygen	11.8	121.9	160.6	177.9	165.4	165.5
	3	air	9.9	81.7	151.4	173.3	178.0	143.8
	4	oxygen	13.5	107.2	139.2	144.5	140.6	132.7
	5	air	9.3	137.2	148.7	152.7	135.1	142.7
	6	oxygen	11.6	139.3	150.1	134.2	128.4	124.7
7	1	oxygen	10.8	88.2	92.6	115.4	131.4	128.9
	2	air	7.7	37.5	85.1	119.1	117.3	115.2
	3	oxygen	7.1	67.8	115.6	122.0	124.7	112.3
	4	air	16.1	53.6	128.3	143.5	150.2	122.9
	5	oxygen	11.1	69.4	127.5	131.4	128.8	116.8
	6	air	18.2	41.4	93.9	104.4	110.1	104.0

PYRUVIC ACID
(mg %)

SUBJECT	TRIAL NUMBER	AFTER BREATHING AIR OR OXYGEN	PYRUVIC ACID					
			pre-exercise	post-exercise samples 1	2	3	4	5
1	1	oxygen	1.16	2.50	3.35	3.91	4.19	4.95
	2	air	1.0	-	-	4.89	4.09	6.20
2	1	air	1.24	2.85	2.50	3.61	5.1	-
	2	oxygen	.89	1.15	2.09	2.76	4.35	6.06
	3	air	1.16	1.46	1.99	2.57	2.86	4.08
	4	oxygen	.94	1.08	1.92	2.78	2.99	4.85
	5	air	1.32	1.65	1.88	4.54	3.40	4.67
	6	oxygen	1.10	1.52	1.69	2.31	3.30	4.35
3	1	oxygen	.91	1.75	2.11	3.46	4.23	-
	2	air	.95	1.83	2.18	3.44	3.35	4.77
	3	oxygen	1.43	2.01	2.28	3.59	4.64	5.62
	4	air	1.07	1.62	1.61	2.46	3.97	3.87
	5	oxygen	1.15	1.33	1.73	1.47	4.05	3.69
	6	air	.97	1.34	1.39	2.63	3.08	3.85
4	1	oxygen	1.30	1.53	2.00	4.15	3.60	3.85
	2	air	1.68	1.84	2.83	3.37	4.80	6.64
	3	oxygen	1.49	1.91	2.81	3.43	4.42	4.15
	4	air	1.42	2.51	4.21	4.32	5.21	4.11
5	1	air	1.53	2.09	2.68	2.89	3.38	4.97
	2	oxygen	1.38	1.87	1.95	2.23	3.75	4.06
6	1	air	1.77	1.98	1.98	2.83	3.94	4.30
	2	oxygen	1.18	1.30	1.84	2.44	3.01	3.65
	3	air	1.50	2.05	2.09	2.97	4.38	4.31
	4	oxygen	1.32	1.80	1.93	3.36	5.19	5.31
	5	air	1.32	1.71	1.78	2.12	3.17	3.76
	6	oxygen	1.42	1.49	1.94	2.91	4.11	4.55
7	1	oxygen	1.34	1.80	2.03	2.57	3.92	4.88
	2	air	0.86	1.56	1.65	1.71	2.66	2.71
	3	oxygen	1.23	1.25	1.44	1.99	2.63	2.82
	4	air	1.06	1.98	2.16	3.20	4.79	5.00
	5	oxygen	1.22	1.33	1.42	2.15	3.09	3.09
	6	air	1.38	1.53	1.67	1.77	2.98	3.07

OXYGEN INTAKE
(in litres/minute)

		pre-exercise	1	2	3	4	5
Air Trials	Total	6.957	42.603	22.08	17.42	13.86	10.76
	Mean	.409	2.506	1.229	1.025	.815	.672
Oxygen Trials	Total	6.239	28.45	19.50	15.20	12.44	10.74
	Mean	.390	1.778	1.219	.950	.778	.671

LACTIC ACID
(mg %)

		pre-exercise	1	2	3	4	5
Air Trials	Total	153.7	1138.3	1744.1	2125.7	2026.8	1903.1
	Mean	9.6	66.3	106.7	132.9	126.7	126.9
Oxygen Trials	Total	155.3	1299.3	1687.9	1873.8	1878.5	1780.2
	Mean	9.7	81.2	105.5	117.1	117.4	118.7

PYRUVIC ACID
(mg %)

		pre-exercise	1	2	3	4	5
Air Trials	Total	20.23	28.00	32.60	49.32	61.16	66.31
	Mean	1.26	1.87	2.17	3.08	3.82	4.42
Oxygen Trials	Total	19.46	25.62	32.68	45.51	61.47	65.88
	Mean	1.21	1.60	2.04	2.84	3.84	4.39

EXCESS LACTATE
(mg %)

		1	2	3	4	5
Air Trials	Total	931.4	1508.2	1766.2	1566.8	1406.1
	Mean	62.1	100.5	110.4	97.9	93.7
Oxygen Trials	Total	1094.9	1435.4	1522.3	1395.1	1249.8
	Mean	68.4	89.7	95.1	87.2	83.3